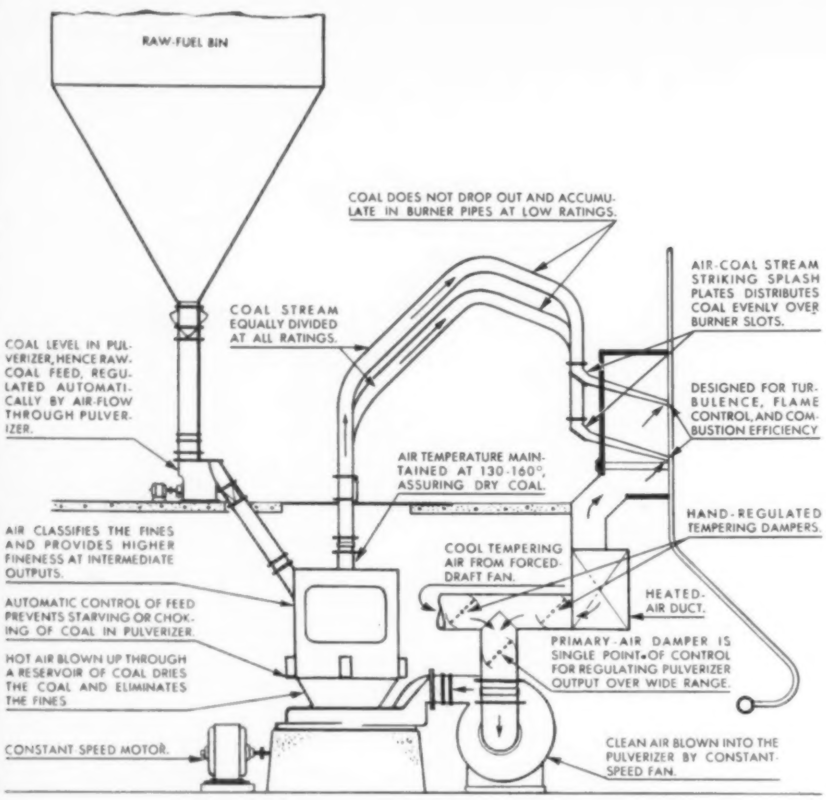
MECHANICAL ENGINEERING

December 1936

In This Issue

PAPERS ON CORROSION-RESISTANT METALS FOR A.S.M.E. 1936 ANNUAL MEETING

In the B&W DIRECT-FIRING SYSTEM



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EASILY • SAFELY • EFFECTIVELY •

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Coal of any moisture that can be transported to the raw-coal bin can be handled by the B&W Direct-Firing System. It passes freely through the feeder and is dried in the pulverizer by heated air blown through the coal reservoir in the grinding zone.

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At the intermediate and lower ranges of output, full pulverizer capacity is utilized to provide fineness higher than standard, with its attendant advantages. This feature is inherent in the design.

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Controlled flow of air through pulverizer thoroughly mixes finely pulverized coal and primary air and distributes this uniform mixture equally to the burner pipes.

Transports the coal—
The primary air carries the fines through the burner pipes and at such a velocity that no coal lodges in the pipes and burners at any rating.

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In any direct-firing system there are certain important requirements that are met only through air-flow. To meet these requirements, or any combination of them, at any time requires the complete coordination that is characteristic of the B&W Direct-Firing System.

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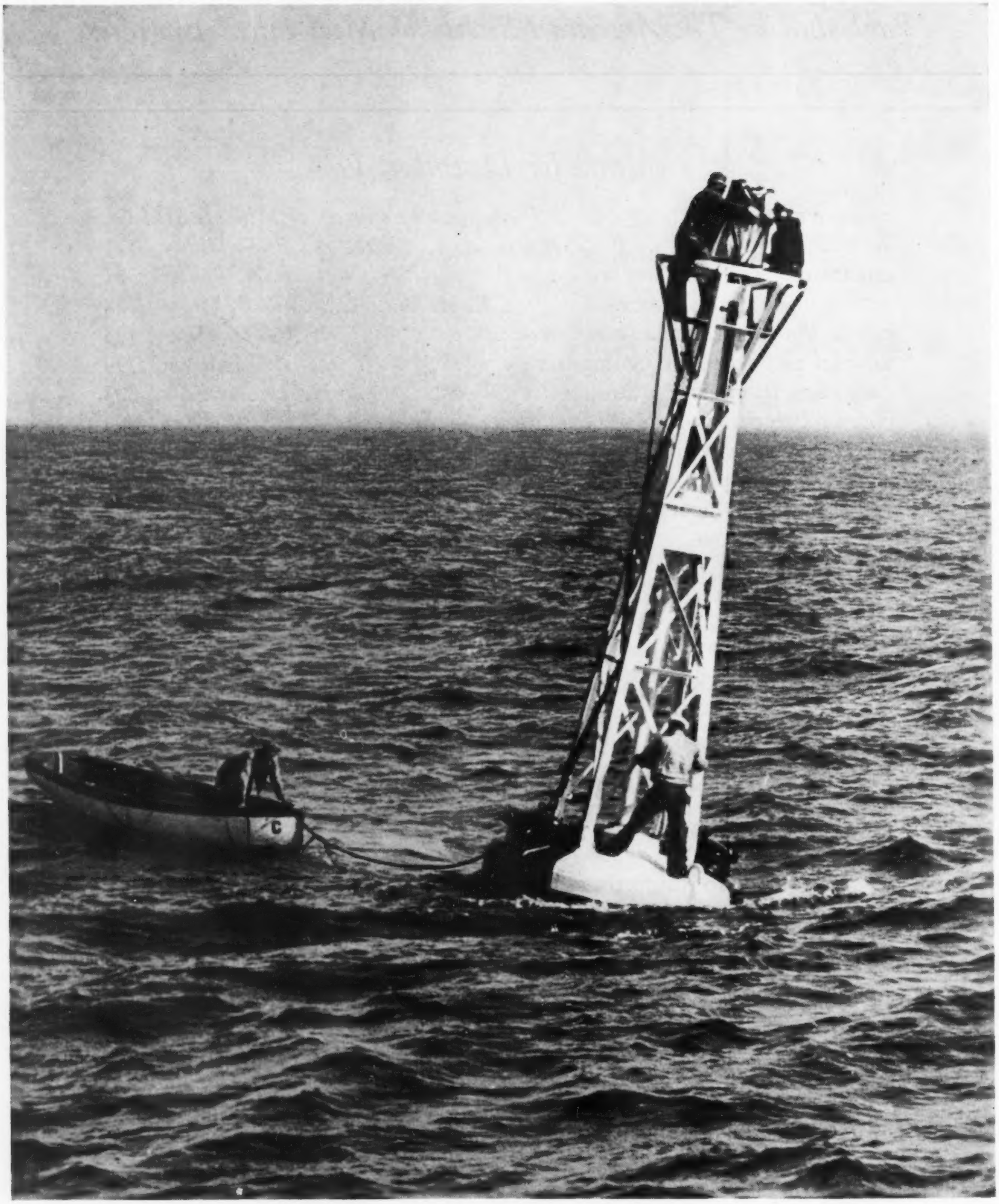

Light Weight and Corrosion Resistance

(A tower buoy off the coast of South Carolina made entirely of aluminum alloy 53S shapes)

Volume 58
No. 12

MECHANICAL ENGINEERING

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1936

GEORGE A. STETSON, *Editor*

The Members' Page

PRESIDENT BATT has had exceptional opportunities for gaging the views of members of The American Society of Mechanical Engineers. For years he has served on committees of the Society and on the Council. He has traveled in the interests of the Society and has discussed Society problems in public meetings and in private conversations. He has talked with members in all parts of the country, and has studied the letters that have been received at headquarters. He believes in the wholesome effectiveness of freely expressed opinions and in the right of members of an organization to state their views in regard to its affairs. Hence he dedicates this month (see page 856) the "Members' Page," a forum for the interchange of views and ideas.

For years Mechanical Engineering has had a correspondence page devoted to "brief articles of current interest, discussions of papers, and A.S.M.E. activities." But few members have ever used this page to express their views on Society affairs. Most of the letters printed have discussed articles appearing in Mechanical Engineering, or topics of general interest to engineers. By setting up an independent forum for the discussion of Society affairs exclusively, it is hoped that members will feel free to offer their opinions and address their fellow members publicly.

In conducting this page no attempt will be made to round up material for it. All letters published will be bona fide contributions to the members' page. Hence communications should be addressed in such a way that the Secretary will know that they are intended for publication. If no material is available at the time of going to press, the members' page will be omitted from that issue.

The members' page will appear in the A.S.M.E. News section of Mechanical Engineering. If a communication is based on a misunderstanding on the part of the member writing it, explanation will be offered before the letter is released for publication, so that the member may be protected from making misstatements publicly. Within the limits of relevancy and good taste, no communication will be ignored because it may be critical. If questions are asked, answers to them, prepared by competent authority, will be published with the letter. The objective aimed at is free expression and understanding.

The success of the page Mr. Batt dedicates this month lies with the members of the Society. So let's have some letters.

Recrudescence of Steam

DURING the last few years high-speed, streamlined trains with Diesel-engine drive have been receiving a great deal of public attention. Presenting an entirely new external appearance and novel interior arrangements and decorations and having names that signify speed and grace, these new trains have caught the imagination of the public. Not to be outdone, steam-locomotive designers have gone in for streamlining and speed, and the railroads have publicized fast runs of steam-powered trains of the new designs. Competition brings change and in change there is often progress.

Although Europe has witnessed several steam railcars, this country has not. Interest attaches, therefore, to the streamlined two-car steam-powered train of the New York, New Haven, and Hartford Railroad, described at the meeting of the New York Railway Club on October 16. This experimental unit, in regular service of 317 miles per day between Bridgeport and Hartford, Conn., consists of two reconstructed 20-year-old steel coaches, in one of which is installed a high-pressure, continuous-flow Besler boiler. A Besler power truck with two high-pressure, compound, condensing Besler engines developing a total of 550 hp forms the motive unit. An air-cooled condenser is located in the roof of the car.

In comparing the new steam-powered railcar with the road's Diesel-driven "Comet," Mr. Cartwright, of the New Haven, said that the Besler train has a fuel consumption of approximately 0.6 mile per gallon of fuel oil, while the "Comet" travels 1.6 miles per gallon, including oil for heating. The new train seats 152 passengers and has a baggage capacity of 3000 lb, while the "Comet" seats 160 and has no baggage space. Other factors are so dissimilar in the two trains as to make comparisons unfair. However, on the basis of the evidence available it would appear that the steam train is one to be considered by the railroads as a competitor of the Diesel-powered train.

These bare facts on the Besler train, which may be read in greater detail in the October 24 issue of *Railway Age*, add interest to the description of the Steamotive, a developmental unit of which is described in this issue of Mechanical Engineering, for its designers had in mind railroad service and two units are already under construction for the Union Pacific. Thus within a short time we shall have performance and maintenance data upon which interesting comparisons between steam and Diesel units can be made.

Among the many interesting features of the new steam

units the novel boilers and the automatic controls demand attention. With but few exceptions American locomotives have stuck to a traditional type of boiler, having fire tubes and a large water and steam capacity, and have been designed for noncondensing operation. Moreover, the use of automatic control devices has been limited. The new high-pressure continuous-flow boilers, on the contrary, have no water-storage drums and are completely automatically controlled—in fact the automatic controls are essential for successful operation. Hence engineers will watch with interest the performance of the new units and the problems in design, construction, and operation that develop.

Corrosion-Resistant Metals

RECENTLY it was our privilege to be shown a paper chart designed for use in a recording thermometer. The surface of this chart is so treated that an ink record made on it can be wiped away by means of a damp cloth with the result that the chart may be used every day for at least two years. By means of this surface the inventor has provided a new material possessing the advantage of economy in use. The illustration is a simple one, but it is typical of what is going on today in the vast field of materials—the improvement of their qualities to extend their application to hitherto impossible tasks.

More extensive illustrations of this widespread improvement in the properties of materials are to be found in the eight papers on corrosion-resistant metals which comprise the bulk of this month's issue. Packed with useful material in usable form, these papers provide designers with needed information. From them the engineers may learn how best to use the cast irons, stainless steels and irons, nickel and nickel alloys, copper and copper-base alloys, aluminum, zinc, and lead in structures subject to corrosion. And what structure, element of construction, machine, or product is not so subject? For progress in engineering has not only brought with it the need for more enduring materials but has introduced processes and kinds of service that the materials available to engineers of former generations could not meet. The petroleum and chemical industries and the exacting requirements of high-temperature and high-pressure service are obvious examples.

The Iron and Steel Division of The American Society of Mechanical Engineers has performed a useful and important service in bringing together the wealth of material represented in these papers, and MECHANICAL ENGINEERING is proud of being the medium through which it is publicly offered to engineers.

Carnegie Again

ENGINEERS will find cause for profound satisfaction in the generous grant of $16,000 by the trustees of the Carnegie Corporation toward support of the program of the Engineers' Council for Professional Development. This grant, which marks another great gift of money from the Carnegie fortune to the engineering profession, will insure vigorous prosecution of the work of E.C.P.D. in raising the status of the engineering profession. It will make possible during a critical period of the Council's growth the full-time services of Gen. R. I. Rees to its work, so that important projects may not be delayed because of lack of administrative zeal. General Rees has already found sufficient time amid the pressure of the duties from which he has just retired to advance vigorously the work delegated to the committee on professional training which he has served as chairman since the inauguration of the E.C.P.D. With his full time devoted to the Council, its immediate prospect is bright indeed.

The problems facing the Council are important and far from simple, and remarkable progress has already been made in view of the brief existence of the Council and the pressure of the normal duties of its members. For example, the committee on student selection and guidance has already made a significant contribution in its studies of the value of certain tests in English and mathematics in determining the aptitude of students for engineering education, as reported in our issue of January of this year. This committee now seeks to add another yardstick in the form of a visualization test which will assist those who advise young men who contemplate engineering as a career—a test which will uncover other essential qualifications than those the English and mathematics tests apparently evaluate. In this endeavor the committee is entering a field in which psychology, as it stands today, is an uncertain guide. Hence this project must wait further progress in that science. However, the work of organized effort on the part of engineering-society groups in various parts of the country in behalf of engineering student guidance will profit greatly by the inspiration and assistance General Rees can bring to it. And so it will be with the projects of other Council committees.

Carnegie's generosity brought engineering societies together thirty years ago by providing a common headquarters for their administrative staffs. For this purpose Mr. Carnegie in 1923 donated the sum of $1,050,000. Later the Carnegie Foundation financed the investigation of engineering education undertaken by a joint committee of the engineering societies, under the directorship of C. R. Mann, and the so-called Mann report of 1918. In 1923 another gift of $118,000 financed the greatest internally directed survey of engineering education that the country has ever witnessed, through which engineering colleges were provided a means for improving their important services, and made possible the summer schools for teachers of engineering conducted by the S.P.E.E. from 1927 to 1933.

This latest contribution to the Engineers' Council for Professional Development brings Carnegie again before engineers as a patron of the profession on which his fortune was based. Through his still-living spirit he is aiding once more the development of the engineering profession.

STEAMOTIVE

A Complete Steam-Generating Unit, Its Development and Test

By E. G. BAILEY,[1] A. R. SMITH,[2] and P. S. DICKEY[3]

STUDIES MADE some few years ago indicated that there should be a good field of application for small steam-generating units of good efficiency, relatively light weight, and small space requirements, in the field of power-generating equipment for installations of small and moderate capacity, say from 1000 hp to 10,000 hp. In order to compete with other prime movers in this field the steam should be generated at as high pressure and temperature as appears feasible; and in order to reduce the operating expense it was agreed that fully automatic control of the steam generation in response to changes in demand would be a very desirable feature.

A number of years ago the General Electric Company, realizing the necessity for improved power for locomotives and other similar applications, and having in mind the early work done by The Babcock & Wilcox Co. and Bailey Meter Co., on high-pressure small-capacity boilers, as exemplified by the Bayonne and Purdue experimental installations, brought to The Babcock & Wilcox Co. the problem of the application of portable steam units to railroad work. This problem was presented on the basis of The Babcock & Wilcox Co.'s supplying a complete steam-generating unit, so designed and constructed as to be suitable for installation in a locomotive in conjunction with turbine-electric drive installed by General Electric Co.

The objects to be attained in the construction of this complete portable steam power plant were as follows:

a High steam pressure and temperature.

b Minimum weight and size per unit of steam produced.

c Wide range of capacity with ability of the unit to respond quickly to wide variations in load conditions.

d Adaptability to wide range of fuels.

e Completely coordinated auxiliaries.

f Completely coordinated automatic control.

g Units to be of simple design and to be constructed in sizes small enough to be portable.

Following preliminary work done jointly by The Babcock & Wilcox Co., General Electric Co., and Bailey Meter Co. to confirm the possibilities, a developmental steam-generating unit was built and put in operation to perfect the design of the various component parts under actual operating conditions. This complete steam-generating unit was called "Steamotive."

The developmental Steamotive unit was assembled in the General Electric works at Schenectady, N. Y., during the latter part of 1934. The Steamotive boiler was designed and built by The Babcock & Wilcox Co., at Barberton, Ohio. It was oil-fired and designed for an output of 21,000 lb of steam per hr at a pressure of 1500 lb and a temperature of 1050 F leaving the superheater, later changed to 900 F. These specifications conformed to the requirements of a steam-turbine-electric locomotive.

The Steamotive auxiliary set was designed and built by General Electric Co. These auxiliaries, geared together as one turbine-driven unit, consisted of a feed pump which delivered 25,000 lb of water per hr at a pressure of 2000 lb; a blower for 30,000 lb air per hr at 60 in. water pressure; a fuel-oil pump; and a lubricating-oil pump.

The meters and complete automatic control, designed and built by Bailey Meter Co., coordinate the auxiliaries and the supply of fuel, air, and feedwater to control steam output, pressure, and temperature, together with complete automatic ignition and safety equipment.

No serious defects were encountered in any of this equipment. During tests the complete unit operated 950 hr, much of which time was at continued maximum rating with long periods under extremely variable load conditions, such as would be encountered in regular locomotive road service. The combustion of oil exceeded 400,000 Btu per cu ft per hr on peaks and 375,000 under continuous load. The unit operated over a range of output of 10 to 1 under complete automatic control.

This Steamotive unit is now in commercial service in the Lynn Works of the General Electric Co.

A complete turbine-generator plant using one oil-fired Steamotive unit has been built for a large industrial concern and is now being installed in one of its small isolated manufacturing plants for supplying electric power and low-pressure steam for building heating. This Steamotive unit has a capacity of 10,000 lb per hr and furnishes steam to the turbine at 1200 lb per sq in. and 950 F.

Two oil-fired Steamotive units, each having a capacity of 40,000 lb per hr, are now being constructed for the Union Pacific Railroad for driving two 2500-hp electric locomotives. These units will furnish steam to the turbines at 1500 lb per sq in. and 950 F.

INSTALLATION OF DEVELOPMENTAL STEAMOTIVE UNIT

The first developmental Steamotive unit was assembled at the Schenectady Works of the General Electric Co. for test. The intention was that two similar units would be installed in the cab of a 5000-hp steam-electric locomotive. The shape and dimensions of the boiler were determined by the proposed locomotive design, which at that time required the boiler to be wholly above the frame, hence necessitating a horizontal boiler.

The flow diagram of the unit is shown in Fig. 1, and the details of construction in Fig. 2. The general appearance and arrangement of equipment constituting the Steamotive unit in its final condition during the later stages of test at Schenectady and as operating at the Lynn Works of the General Electric Co. today is shown in Fig. 3.

From the burner the flame and gases pass horizontally through the completely water-cooled furnace, thence up and back with a 180-deg turn into the superheater, flowing around the separator, through the economizer and air heater and up the stack. The air for combustion leaves the blower at relatively high pressure, passing through lanes intersecting the stack and down around the air-heater tubes to the oil burner. There is no induced-draft fan, the blower forcing the air through the burner and furnace under pressure.

The feedwater enters the economizer inlet header, and, after

[1] The Babcock & Wilcox Co., New York, N. Y. Mem. A.S.M.E.

[2] General Electric Co., Schenectady, N. Y. Mem. A.S.M.E.

[3] Bailey Meter Co., Cleveland, Ohio. Mem. A.S.M.E.

Contributed by the Power Division for presentation at the Annual Meeting, New York, N. Y., November 30 to December 4, 1936, of The American Society of Mechanical Engineers.

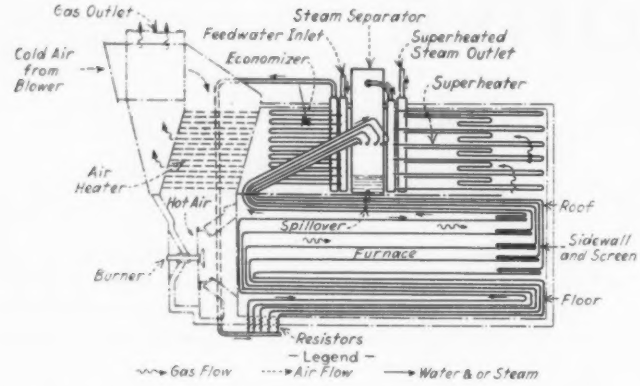


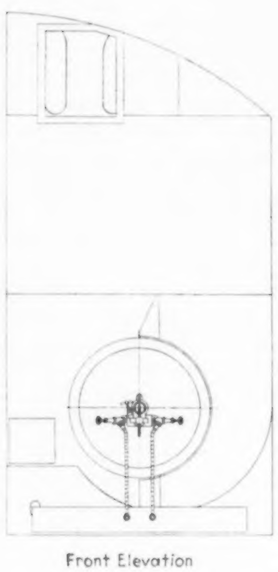
FIG. 1 FLOW DIAGRAM, DEVELOPMENTAL STEAMOTIVE BOILER

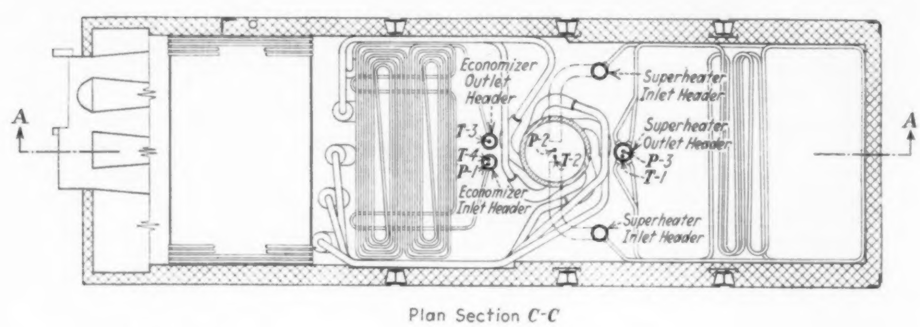
leaving the outlet header, is divided into five circuits, all five of which form the floor, sides, and roof of the furnace as well as the two sets of loops forming the boiler screen. All the steam is generated in these five furnace and boiler circuits and enters the separator with a surplus of about 400 lb of water per hr in each circuit. From the separator the dry steam goes through the superheater and directly to the main turbine. The water from the separator is called the "spillover," and it passes through a heat exchanger to the hot well where it mixes with the condensate and is re-fed to the boiler by the feed pump.

DESCRIPTION OF BOILER

Burner. The burner is of a special, short-barrel, steam atomizing, wide-range design. Guide vanes are provided to secure even distribution of the air to the burner. A pilot gas burner is provided for ignition, and is fed with propane gas stored in portable cylinders. A photoelectric flame-failure indicator is located in the burner box. This cell "sees" the flame through the opening between the burner throat and the impeller plate.

Furnace. The furnace is approximately 3 ft 6 in. wide and 3 ft 6 in. high inside the tubes and 7 ft 6 in. long from the burner wall to the boiler screen tubes. The furnace volume is 90.4 cu ft. The only refractory in the furnace is in the burner wall. The floor, sides, and roof of the furnace are formed by closely spaced tubes. There are five circuits in parallel in the furnace





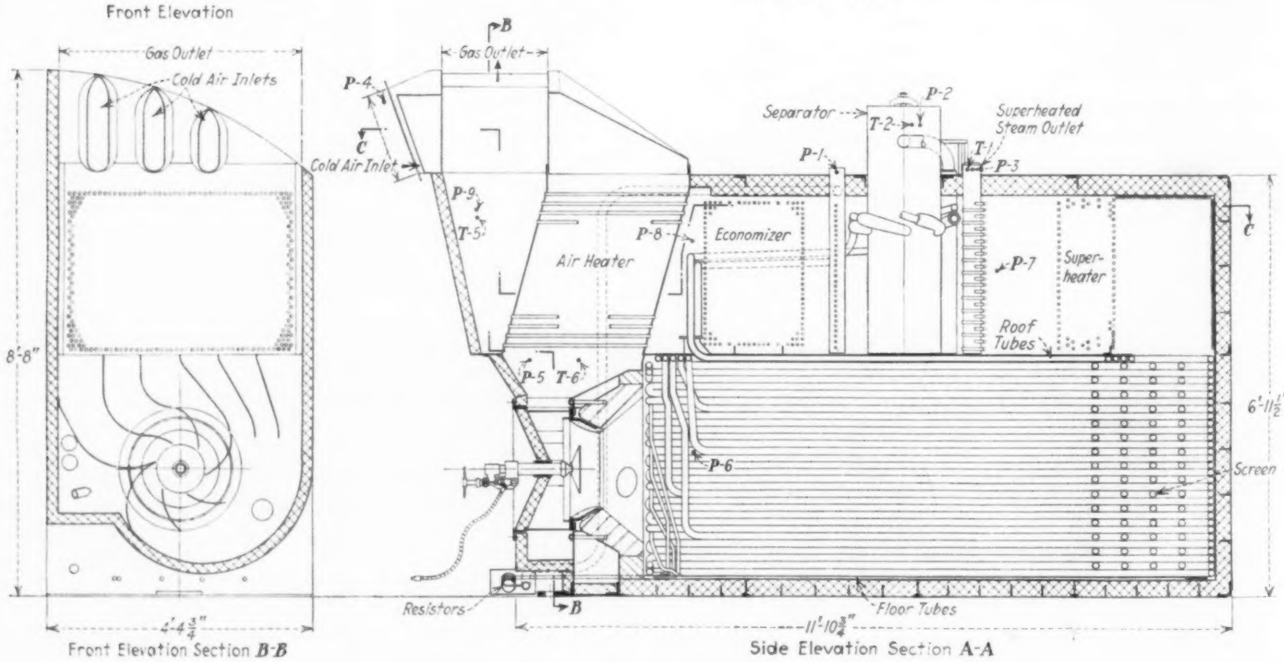


FIG. 2 DETAILS OF CONSTRUCTION, DEVELOPMENTAL STEAMOTIVE BOILER

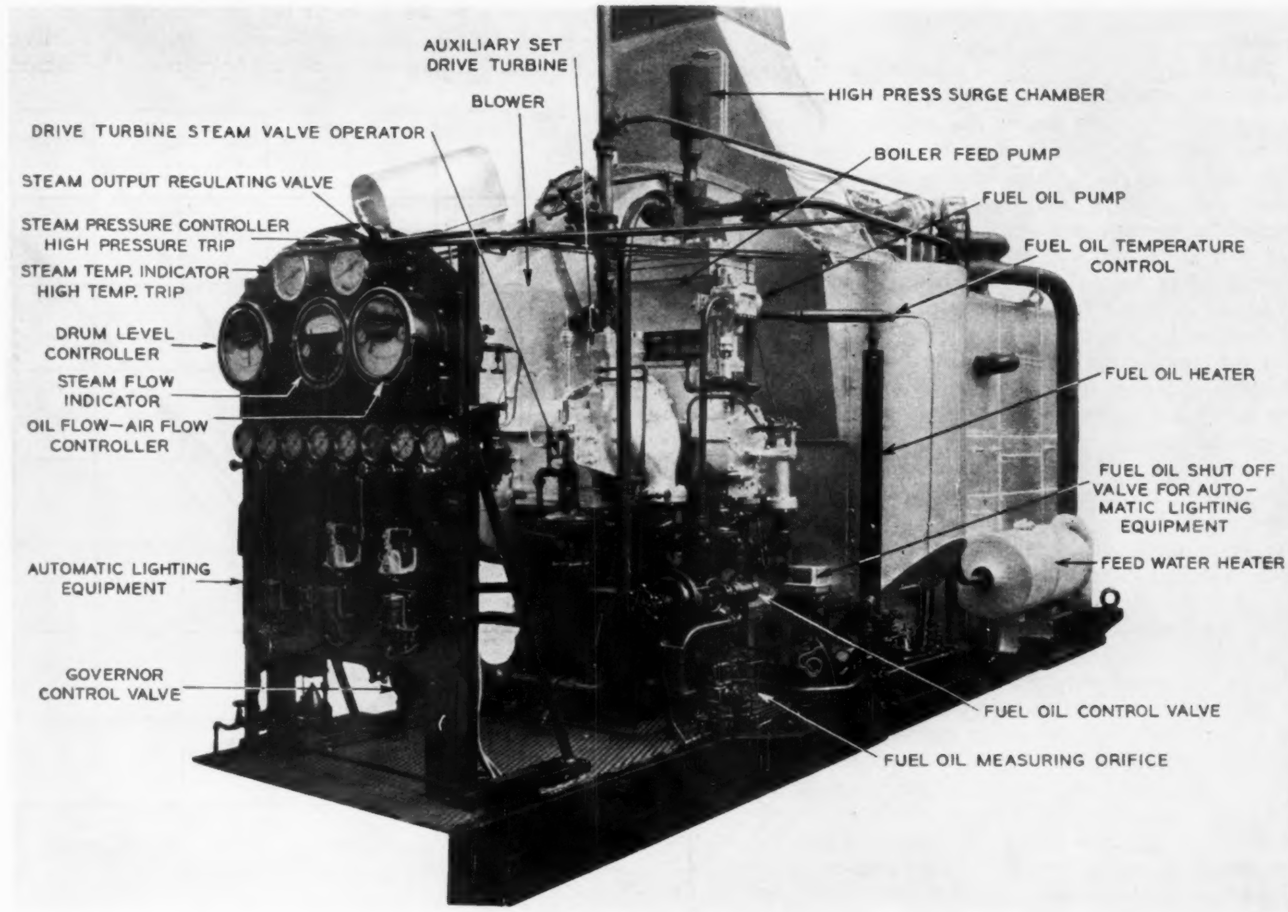


FIG. 3 GENERAL ARRANGEMENT OF EQUIPMENT, DEVELOPMENTAL STEAMOTIVE UNIT

and boiler screen. The five circuits in the floor, side walls, and roof are connected in such a way as to balance as nearly as possible the heat input to each of the five combined circuits. The length of each floor circuit is 92 ft 9 in. The average length of each wall circuit is about 183 ft 6 in., and the average length of each roof circuit is about 49 ft, giving a total average length of each furnace circuit of approximately 325 ft.

Superheater. Due to the removal of excess surface the superheater occupies only about one third of the available space. The roof, rear wall, and side walls of the cavity in the rear of the superheater are lined with closely spaced superheater tubes forming a radiant section, the purpose being primarily to protect the inner casing plates from excessive gas temperature.

The superheater tubes are KA2S (18 per cent chromium, 8 per cent nickel), supported by alloy-steel rods hung from the roof with springs to take up differential expansion. The superheater inlet headers are of seamless carbon steel and the outlet header is of forged KA2S. Except for the inlet and outlet ends the headers are within the casing and uninsulated.

Economizer. The economizer consists of 29 vertical rows formed by flat coils which give the equivalent of 18 horizontal rows. The coils are hung from the roof by alloy rods in the same way as the superheater. The inlet and outlet headers are inside the casing, and are made from seamless carbon-steel tubes. A tube connects the economizer outlet header to the five furnace floor circuits below the burner. Coiled resistor tubes are connected between the economizer outlet and the floor circuit inlets to introduce a definite pressure drop to insure equal water distribution to each furnace circuit.

All tube connections are made by the fusion-welded process and each circuit is continuous without flanged or expanded connections. All tubes are strength-welded to headers and drums. The tubes and separator drum are designed for a factor of safety of five.

Air Heater. The air heater is made up of 1515 tubes, 2 ft 4 in. long, and the rows are spaced on one-inch horizontal and $^{15}/_{16}$-in. vertical centers staggered. The tube ends are welded into the steel tube sheets. The gas flows inside the tubes and the air cross-flows outside. The air connection at the front of the boiler crosses the gas outlet to the air-heater inlet by means of three streamlined ducts. The contour of the gas outlet corresponds to that of the locomotive roof.

Heating Surface. The boiler heating surface is as follows:

Furnace projected surface, sq ft	112.3
Boiler-screen convection surface, sq ft	115.9
Superheater projected radiant surface, sq ft	30.5
Superheater convection surface, sq ft	127.8
Economizer, sq ft	275
Air heater, sq ft	578

Separating Drum. The separating drum is located in the top of the boiler extending through the top casing $13^5/_8$ in. with the bottom near the furnace roof plate. The drum is supported from structural work in the top casing. The furnace roof plate is attached to the bottom of the drum as well as the superheater and economizer headers for additional support.

The inlet connections from the five furnace circuits enter the drum tangentially, with the ends of the tubes flattened.

The two steam-outlet connections are located 180 deg apart

with the center line $18^1/_4$ in. above the center line of the inlet connections.

Boiler Casing. The casing and structural work was designed for a static pressure of 60 in. of water. It is necessary that the casing remain gastight against this pressure and it was decided to make the outer casing tight by all-welded construction. The outer casing plates are of carbon steel and the inner plates of heat-resisting alloy. The outer plates also form an integral part of the strength members welded to the six vertical I-beam and four angle buckstay columns. The casing and supports were designed for a shock load endways and a side sway or turn-over loading $2^1/_2$ times the static load.

Auxiliary Set. In order to save space and complexity of control and improve the efficiency of the boiler auxiliary drive to the highest degree, it was agreed that a combined drive for all the boiler auxiliaries would be an essential feature. These auxiliaries consist of a feedwater pump of the positive-displacement type, a blower for furnace combustion air, and a fuel pump of the positive-displacement type. Roughly speaking, the demands for combustion air and fuel oil are proportional to the steam output of the boiler, and in this particular type of boiler the feedwater demand is always in excess of the steam output of the boiler. The characteristics of the various auxiliary requirements are such that the relative speeds of all three auxiliaries should be high for high boiler steam outputs and low for low steam outputs. This makes possible the gearing of the three component parts in a fixed ratio and driving them by a single variable-speed steam turbine. Thus the entire set runs at a speed determined by the steam output of the boiler with modification to the blower output by means of a damper, and to the fuel-oil output by means of a by-pass on the fuel-oil pump, with the feedwater-pump output as the independent variable from which the speed of the entire set is determined. The relative performances of the three component parts are determined as shown on the composite curves Figs. 4 and 5. The boiler feed pump is designed to deliver the necessary full-load feedwater flow to the boiler at 100 per cent speed. At this same speed the combustion-air blower is designed to deliver, say, 10 per cent extra air so that it can be controlled by damper-

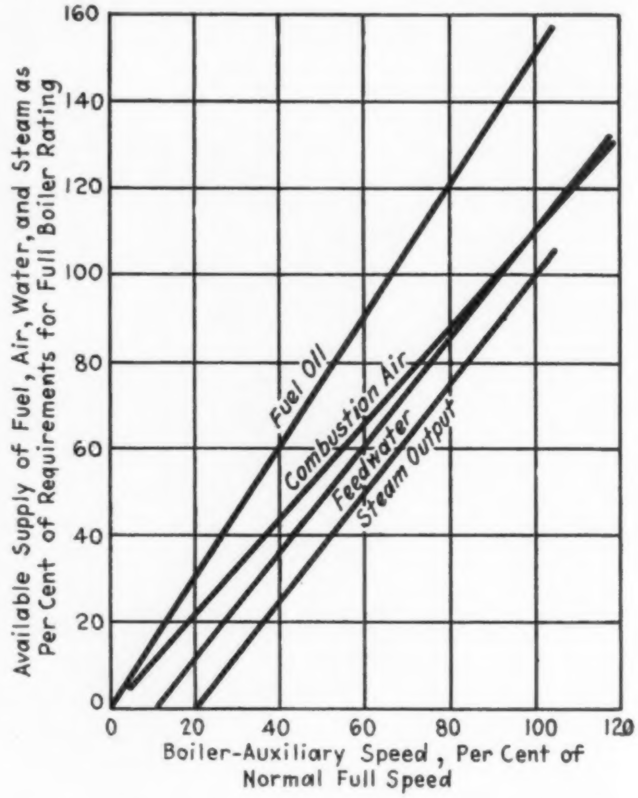


FIG. 4 CHARACTERISTICS OF AUXILIARY SET, DEVELOPMENTAL STEAMOTIVE UNIT

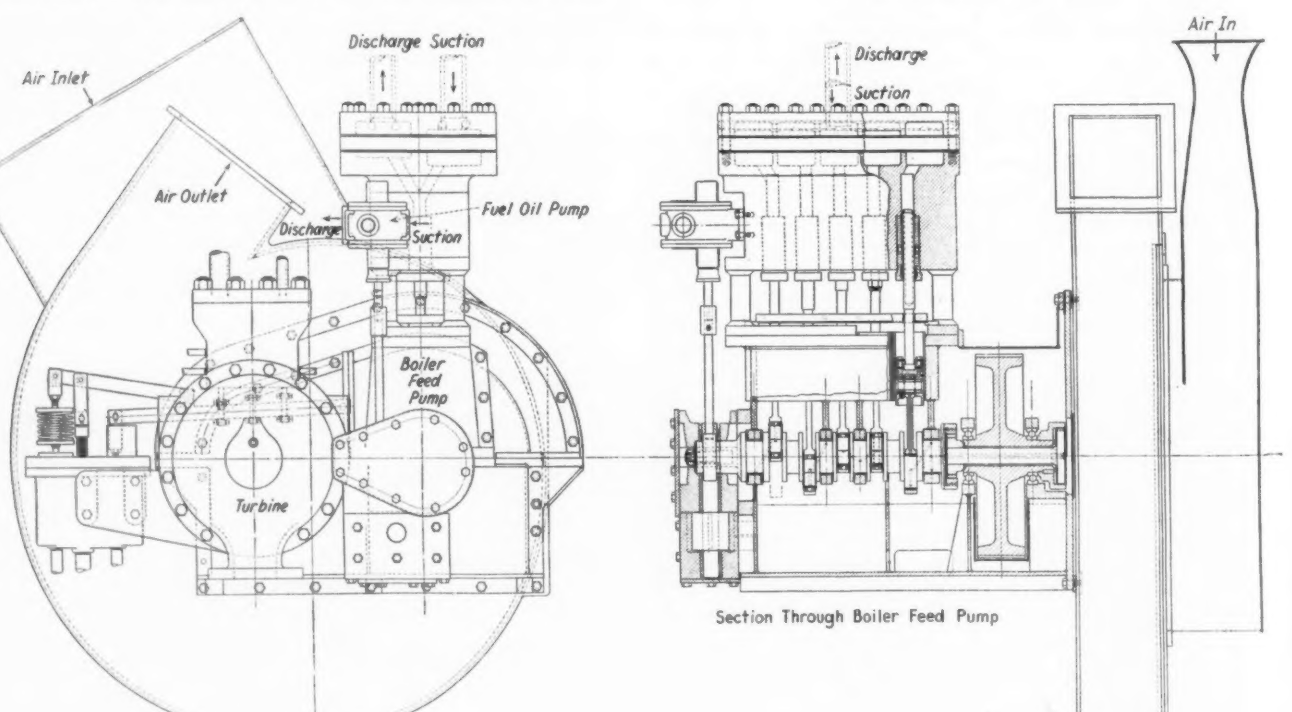


FIG. 6 DEVELOPMENTAL

ing. The fuel-oil pump is given a wide margin of extra capacity in order to take care of possible wear in its parts and also because its power requirements are relatively insignificant, and it is made a final variable dependent upon the air supply. The characteristic requirements of feedwater flow to the boiler due to the constant quantity of spillover water forces the auxiliary

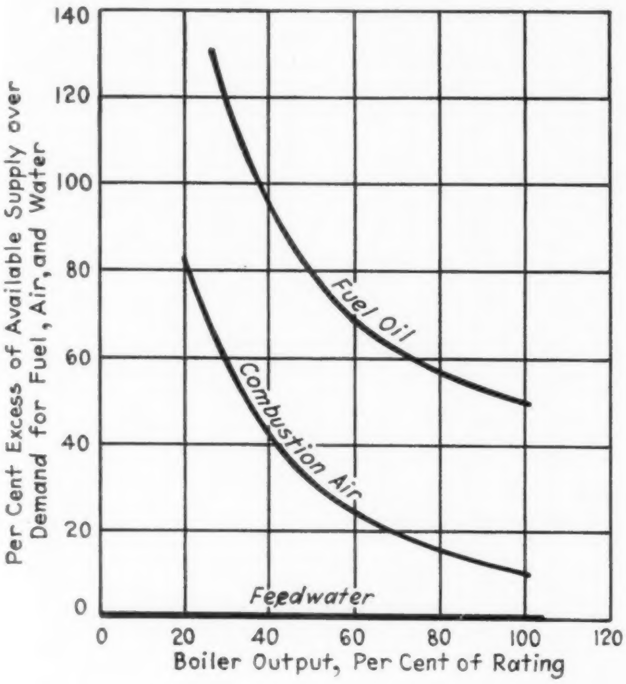


FIG. 5 CHARACTERISTICS OF AUXILIARY SET, DEVELOPMENTAL STEAMOTIVE UNIT

to run at somewhat higher speeds at less than full load than would be required by the combustion-air blower, as a consequence of which the combustion-air excess available is always greater at lower loads than at full load.

The particular auxiliary unit which was built for the developmental set is shown in various cross sections in Fig. 6.

The turbine runs at relatively high speed driving a pinion meshing with a high-speed gear on the blower shaft. This same shaft carries the low-speed pinion which meshes with a low-speed gear on the boiler-feed-pump shaft. From the boiler-feed-pump shaft on its outboard end the fuel-oil pump and the lubricating-oil pump for the set are driven through a pair of spiral gears. The turbine for the developmental set is a relatively simple machine of only one stage.

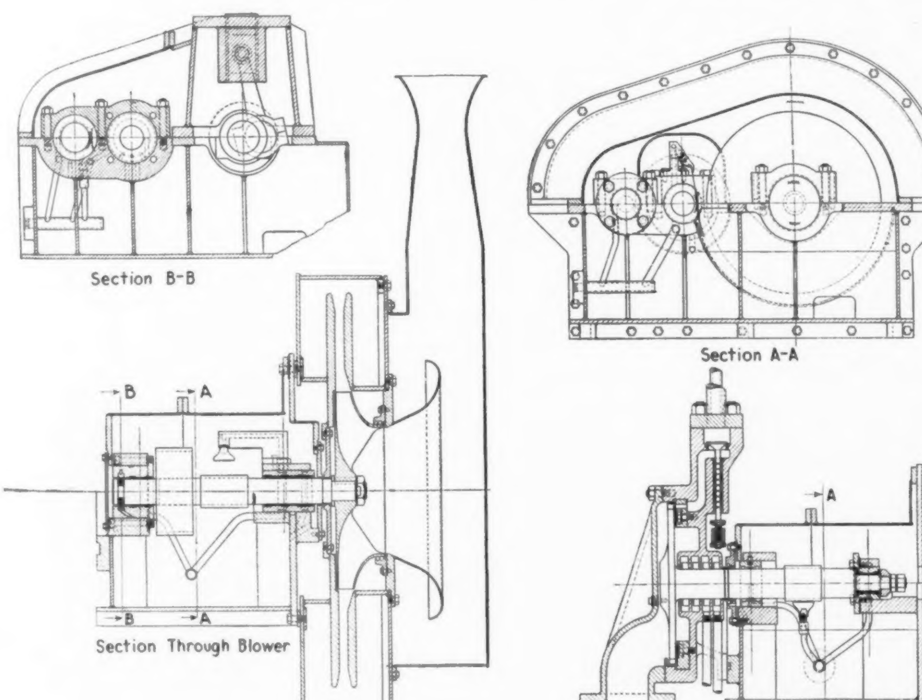
The combustion-air blower is a centrifugal compressor having a maximum discharge head of about 60 in. of water. The boiler feed pump is a single-acting five-cylinder piston pump running at a normal full speed of about 800 rpm with pressure lubrication of the crankshaft pins and connecting rods and crosshead wrist pins. Relatively speaking, for its capacity and high-pressure service it is of small size and light weight. The pump inlet is supercharged to a pressure of about 75 lb to avoid any possibility of cavitation due to the rapid motion of the pistons and the valves. The valves themselves are of hardened steel on hardened-steel seats of approximately 1 in. diameter and from 0.03 to 0.05 in. lift. With such small valves it is essential that no dirt particles of any size be allowed to enter the pump and a good fine-mesh strainer is provided at the pump inlet. Fig. 3 shows the unit as it was finally assembled, illustrating relative proportions and compactness of the design.

Automatic Control. The automatic-control equipment is shown diagrammatically in Fig. 7.

In view of the limited amount of water and heat storage in Steamotive units and since all natural circulation is eliminated, it is of utmost importance in operating this unit that water be fed as nearly as possible equal to the rate of steam output plus spillover. To accomplish this purpose the speed of the auxiliary set is governed to maintain any desired water flow from the feed pump.

The desired rate of water flow is established by measured indications of total boiler steam flow and separator-drum level, and the variable water-flow governor regulates the speed of the turbine driving the auxiliary set to maintain this water flow regardless of variations in steam or water pressure, feed-pump efficiency, or other variables.

One of the important principles upon which the Steamotive unit is designed is that of maintaining an excess of water leaving the evaporating furnace circuits. The quantity of this spillover water delivered into the separating drum is maintained constant at all out-



STEAMOTIVE AUXILIARY SET

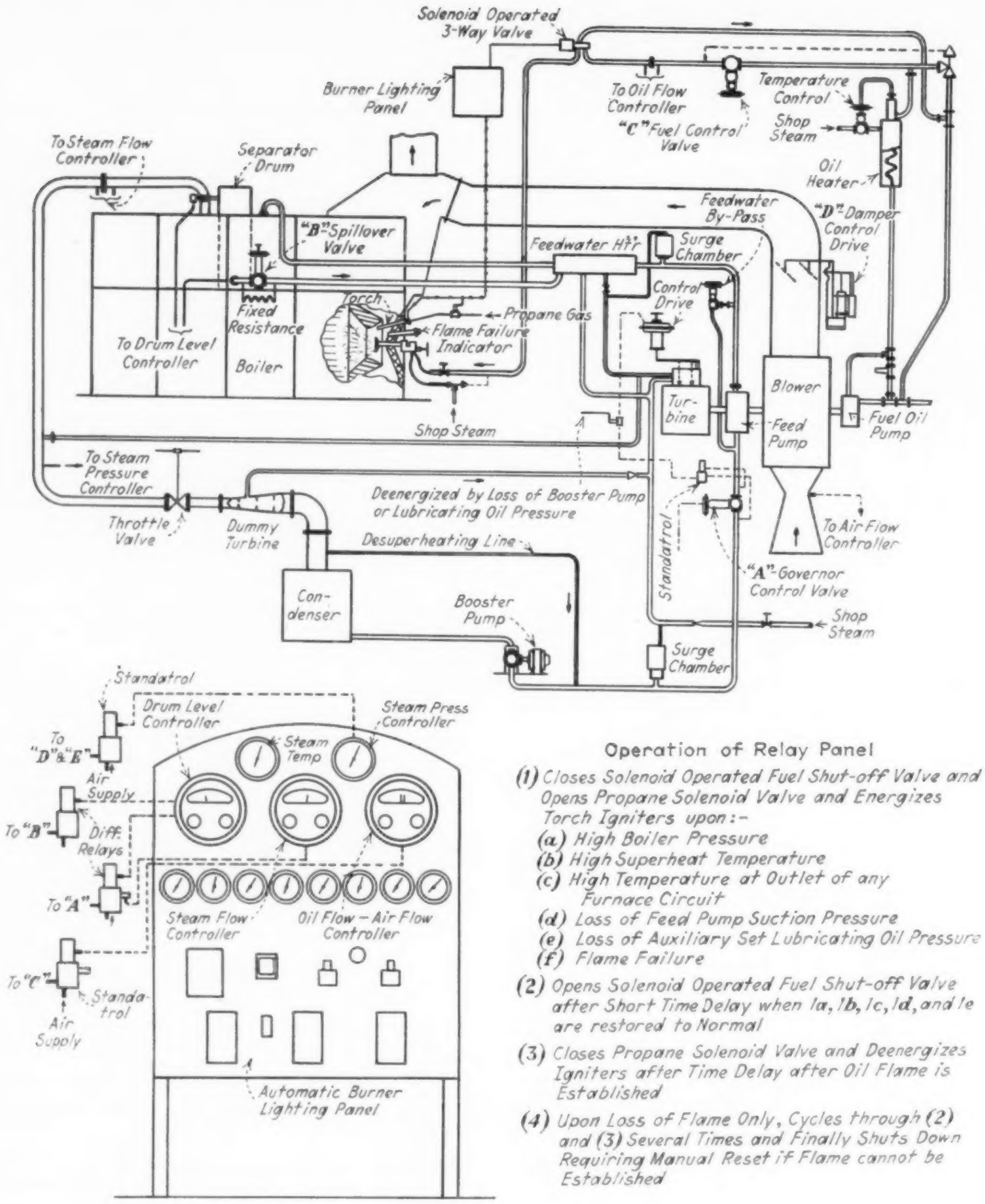


FIG. 7 DIAGRAMMATIC LAYOUT, DEVELOPMENTAL STEAMOTIVE UNIT

puts. The excess water flow is secured by means of a fixed-resistance tube connected to the bottom of the separating drum which will discharge the desired quantity of water with a given difference between drum and back pressures. A constant water level in the separating drum is maintained by the automati control which adjusts feed-pump delivery, which is greater than steam output by the amount of spillover.

The fixed-resistance tube for normal spillover is in parallel with the automatic spillover valve which opens when the water level exceeds the normal limit, quickly bringing the level back to normal by means of the large increase in spillover.

The auxiliary set is designed to provide an excess of air and oil at any given feed-pump speed and the automatic-control equipment is arranged so that necessary throttling of both is provided to maintain a constant steam pressure at the boiler outlet. In addition, the ratio of fuel and air is closely controlled in accordance with metered indications of each so as to maintain the minimum allowable excess air for good combustion.

The burner is provided with a propane torch with dual spark ignition and with a photoelectric flame indicator. A three-way valve is provided in the oil line to the burner to shut off automatically the fuel-oil supply to the burner and recirculate the oil to the suction side of the oil pump. This three-way valve, the solenoid valve in the propane line to the torch, and the spark igniters for the torch are interlocked to perform the following functions:

1 Upon closure of the lighting switch, the igniters are energized and the propane valve opens, lighting the torch. After a short delay, the fuel-oil control valve is opened to the burner, and as soon as ignition of the oil fire is established, as indicated by the photoelectric flame detector, the propane torch and igniters are cut off after a short time delay.

2 The fuel oil is shut off in case of

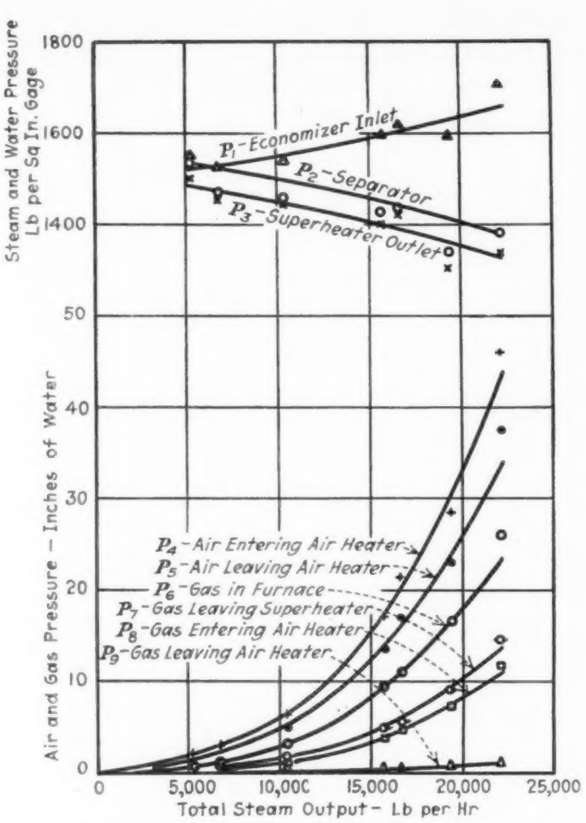


FIG. 8 PERFORMANCE-TEST DATA, DEVELOPMENTAL STEAMOTIVE UNIT

(See Fig. 2 for location of temperature measurements.)

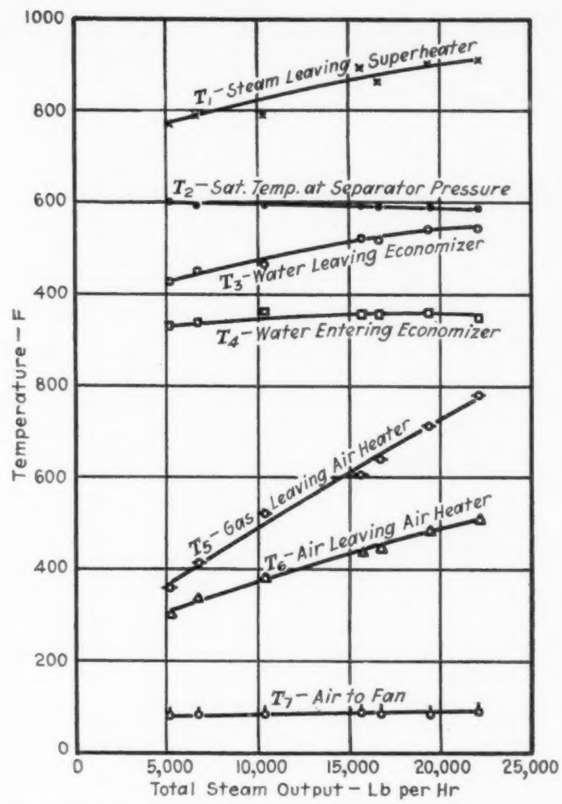


FIG. 9 PERFORMANCE-TEST DATA, DEVELOPMENTAL STEAMOTIVE UNIT

(See Fig. 2 for location of temperature measurements.)

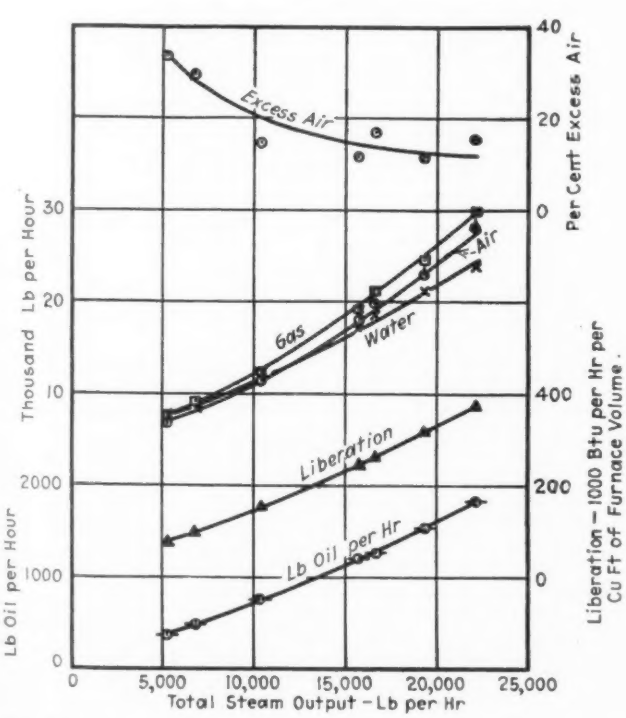


FIG. 10 PERFORMANCE-TEST DATA, DEVELOPMENTAL STEAMOTIVE UNIT

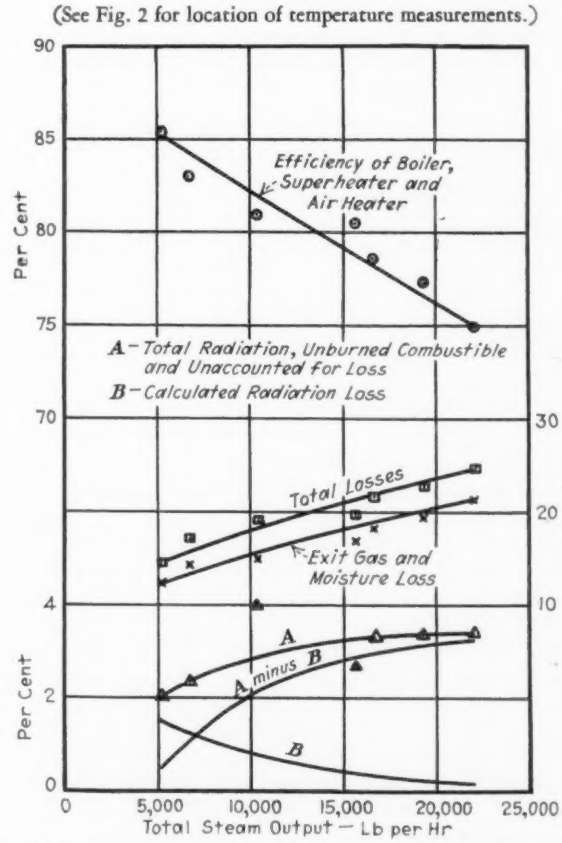


FIG. 11 PERFORMANCE-TEST DATA, DEVELOPMENTAL STEAMOTIVE UNIT

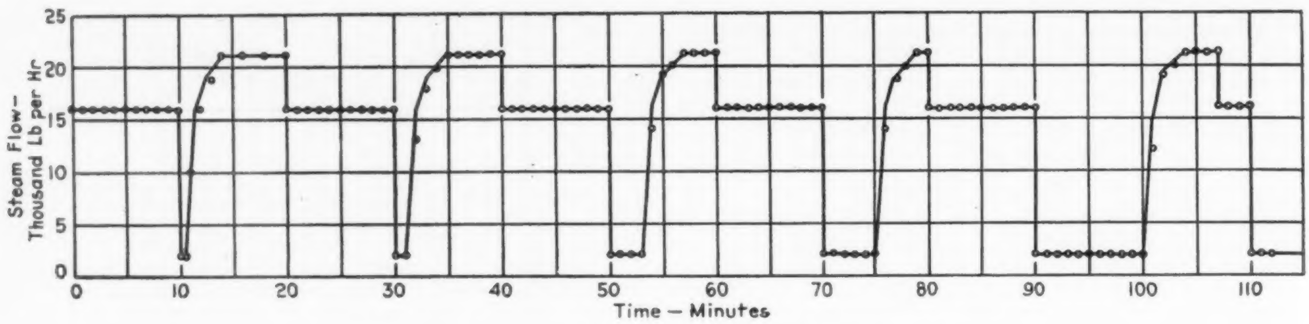


FIG. 12 POWER-DEMAND CURVE, DEVELOPMENTAL STEAMOTIVE UNIT

a High boiler pressure
b High superheat temperature
c High temperature at outlet of any furnace circuit
d Flame failure.

3 The oil burner is automatically relighted as in Par. 1 when 2*a*, 2*b*, and 2*c* are restored to normal.

4 Upon loss of flame only, the relighting cycle is repeated several times, and if flame cannot be established, the unit is shut down, requiring manual reset.

5 Upon loss of feed-pump suction pressure or loss of auxiliary-set lubricating-oil pressure, the oil fire and torch are cut off and the air supply to the governor of the auxiliary-set turbine is likewise cut off, shutting down the auxiliary set.

TEST RESULTS

Operating and heat-balance data obtained from final tests are given in Figs. 8, 9, 10, and 11. Before the tests were begun there was some apprehension about being able to reach the desired capacity of 21,000 lb of steam per hr with any reasonable combustion efficiency. Although the design capacity for continuous running was for 16,000 lb steam per hr, the unit ran 40 continuous hours at 21,000 lb per hr and was tested up to 22,000 lb per hr, which was the limit of the blower for continuous operation.

At the normal load rate of 16,000 lb of steam per hr the feedwater pressure entering the economizer is 1610 lb and the steam pressure at the superheater outlet is 1390 lb, there being a 220-lb pressure drop through the economizer, boiler, and superheater. The steam temperature leaving the superheater at an output of 16,000 lb per hr is 870 F, rising to 910 F at 22,000 lb per hr and dropping to 770 F at 5000 lb per hr.

The air pressure entering the air heater is 18 in. of water at a steaming rate of 16,000 lb per hr, which increases to 43 in. at a rate of 22,000 lb per hr. The air entering the burner is 450 F at a rate of 16,000 lb per hr and 500 F at a rate of 22,000 lb per hr. Combustion is complete within this range of output with less than 15 per cent excess air, and combustion rates from 25,000 to 375,000 Btu per cu ft of furnace volume per hr.

The boiler efficiency varies from 75 per cent based on the high heat value at a rate of 22,000 lb per hr up to 85.5 per cent at a rate of 5000 lb per hr. These efficiencies are 4 to 5 per cent higher than those originally anticipated from the limited heating surface permitted under the conditions to be met in locomotive design.

Fig. 12 shows the type of load-cycling tests which were made on the unit to determine its suitability for performance on a high-speed locomotive. The solid line on the curve indicates the desired load cycle and the plotted points show the actual ratings reached by the boiler at each particular time.

The load-cycle tests on the unit were in two periods of 80 and 267 hr duration. Approximately 450 cycles from minimum to maximum load were made. The total operating time of the unit at Schenectady was 950 hr.

Fig. 13 shows results of a typical test made to determine the flexibility of this unit. This simulates a station stop of a locomotive, when the steam flow, except for driving the auxiliary set, is quickly shut off. The unit continues at a low load for three minutes when the throttle is opened, increasing the steam flow to approximately 16,000 lb per hr in one minute and to 20,000 lb per hr in $2^1/_2$ min. The effect of these load changes upon steam pressure, steam temperature, water level in the

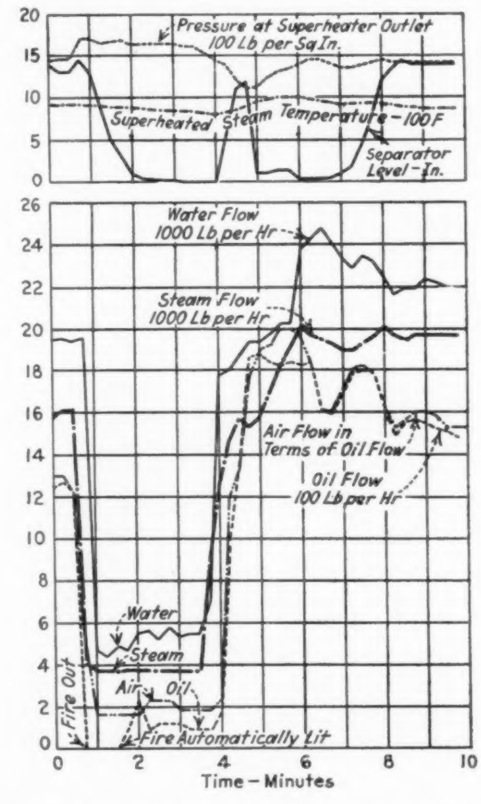


FIG. 13 LOAD-SWING TEST, DEVELOPMENTAL STEAMOTIVE UNIT

separating drum, water flow, air flow, and oil flow are clearly shown.

During these load-cycle tests, such as shown in Fig. 13, oil was burned at rates well above the maximum output rate for short periods during the load pickup, and during some of these periods the liberation was as high as 500,000 Btu per cu ft of furnace volume per hr with low excess air, complete combustion, and freedom from smoke.

Fig. 14 shows how quickly the boiler may be placed in ser-

vice from a completely cold condition, except that the auxiliary set was driven from an external source. Note that the boiler is steaming at reduced pressure within 4 min and has picked up to full load with normal pressure and temperature after 6 min more.

FUEL OIL

The fuel oil used during the tests at Schenectady was Bunker C, having a typical analysis as follows:

Carbon, per cent	87.8
Hydrogen, per cent	10.2
Sulphur, per cent	0.7
Oxygen and nitrogen, per cent	1.3
Btu per lb	18470
Specific gravity, A.P.I. at 60 F	11.9
Bottom sediment and water, per cent	4.0

	Saybolt Furol	Engler
Viscosity at 152 F	28 sec	7.2 deg
Viscosity at 180 F	17 sec	3.6 deg

FEEDWATER

Boiler feedwater for the Schenectady tests was obtained from the condenser hot well treated with caustic soda to obtain a pH value in excess of 11.

In operating the unit the spillover water was returned to the hot well after passing through a feed heater. Concentration in the feedwater was thus only increased in the furnace circuits, depending upon output, reestablishing the average concentration by mixing spillover and condensed steam in the hot well.

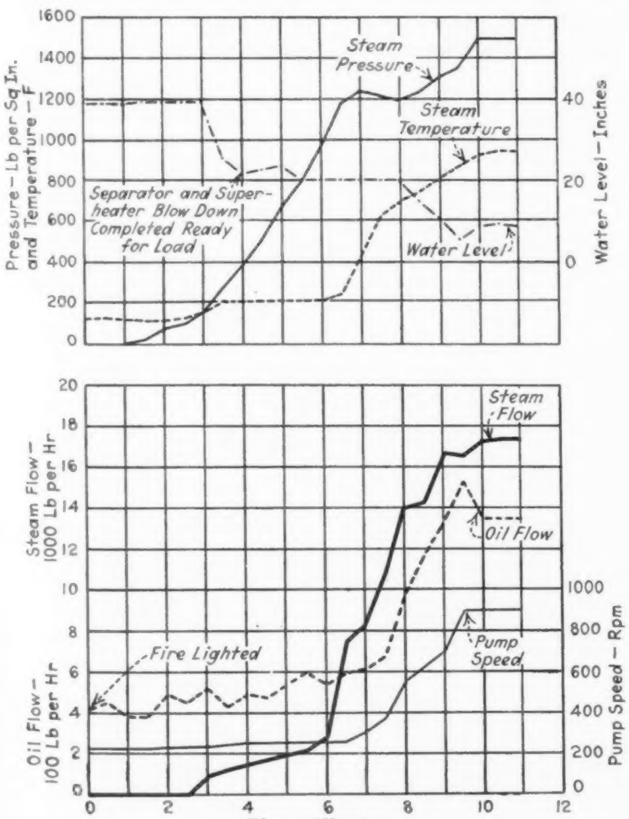


FIG. 14 COLD-STARTING TEST, DEVELOPMENTAL STEAMOTIVE UNIT
(Unit had been shut down for 16 hr prior to lighting up for this test.)

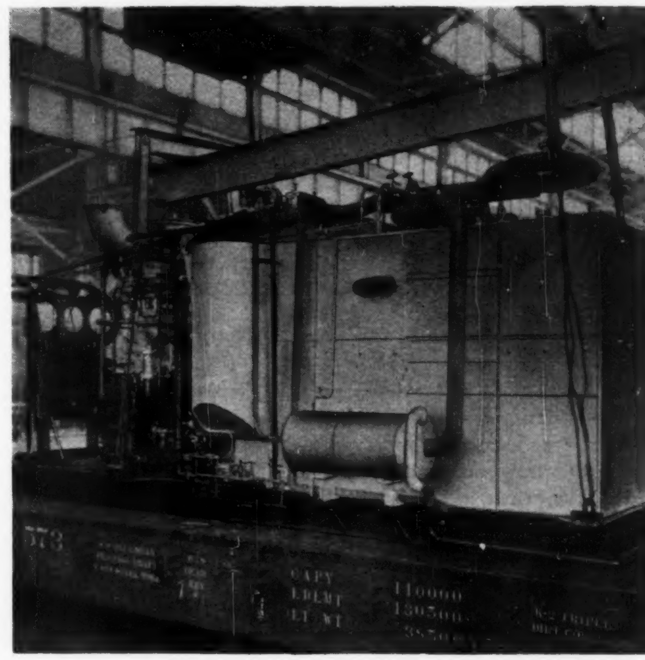


FIG. 15 DEVELOPMENTAL STEAMOTIVE UNIT ON FLAT CAR FOR SHIPMENT

Typical analyses of feedwater and spillover water from the separating drum are given in Table 1.

TABLE 1 ANALYSES OF FEEDWATER AND SPILLOVER

	Boiler feed, ppm	Spillover water at 20,000 lb per hr steam output, ppm
$CaCO_3$, calcium carbonate	Trace	1.3
NaOH, sodium hydrate	12.0	130.0
Na_2CO_3, sodium carbonate	10.4	20.9
Na_2SO_4, sodium sulphate	0.4	4.1
NaCl, sodium chloride	0.8	8.2
Iron dioxide and alumina	0.3	0.3
Silica	1.5	3.5
Oil	1.0	3.0
Organic matter	4.9	46.2
Suspended matter	Trace	Trace
Total solids	31.3	217.5

INSTALLATION AT LYNN WORKS

After completion of the tests at Schenectady it was decided to make a portable unit mounted on a structural base that could be handled and shipped intact. Boiler, auxiliary set, and control are arranged as shown in Fig. 3. A high-pressure boiler was required at the Lynn Works of the General Electric Co. to test marine turbines and the Steamotive unit met the requirements nicely. The probability of installing this particular unit in a locomotive in the near future seemed remote, and it was concluded that the first installation in a locomotive would require changes in certain details and a different heat balance would affect the general design. For these reasons the unit was shipped to Lynn ready for a testing schedule which started January 1, 1936. Since that time—to date—the unit has conformed to the testing schedule required and has given satisfactory performance. The unit mounted on a flat car ready for shipment to the Lynn Works is shown in Fig. 15.

PROPOSED BOILER ARRANGEMENT

Fig. 16 indicates an improved design of Steamotive unit after experience with the developmental unit at Schenectady and Lynn. This boiler is vertically fired. The furnace is circular in cross section. There are two intermediate open passes between the furnace and superheater which require the gases to make three 180-deg turns. The furnace and two open passes are completely water-cooled with studded or bare-tube construction. The furnace tubes are fully studded and the open-pass tubes are bare or partially studded. The maximum capacity of this boiler is about the same as the original developmental unit.

CONCLUSION

1 Tests made on the developmental Steamotive unit and subsequent design studies indicate that a steam-generating unit of this type is entirely practical for generation of high-pressure and high-temperature steam.

2 The principal advantages of this type of unit over natural-circulation boiler installations are the small space required and the reduction in weight of the unit.

3 It is possible to fit this type of boiler into a restricted space and the design is flexible in its adaptability to limits in height, width, or length.

4 Minimum weights and volume in a high-pressure steam generator require, (*a*) high furnace release rates, (*b*) high convection transfer rates, (*c*) small tube diameter, (*d*) minimum tube thickness, (*e*) forced circulation in steam-generating tubes, (*f*) practical elimination of refractory walls, (*g*) simple and compact auxiliary equipment, and (*h*) shape of boiler approaching a cube.

5 High convection transfer rates require high draft loss. Transfer rates, exclusive of the radiation component, vary as approximately the two-thirds power of gas mass flow. Draft loss varies as approximately the square of gas mass flow, and will increase as approximately the cube of the convection transfer rate.

6 The elimination of refractory in the furnace and boiler setting, replaced by waterwalls and insulating block, not only results in a large saving in weight and volume, but also in reduced heat capacity that materially affects the ability to change output quickly. The small water content of the forced-circulation boiler results in quick response to load changes and insures safety in spite of the high-temperature and high-pressure steam conditions. These factors permit quick starting from a cold condition, requiring less than ten minutes from lighting the burner to full output.

7 It has been found that combustion liberation rates up to 400,000 Btu per cu ft per hr can be obtained with low excess air and smokeless combustion with oil fuel.

8 The pressure furnace which utilizes forced draft only is entirely practicable and materially simplifies the draft equipment and control therefor.

9 The wide-range burners used on this unit and the coordinated auxiliary set make complete automatic control a thoroughly practicable device. Completely automatic lighting of the burners has been entirely satisfactory and the use of safety devices which automatically cut off the oil fire have proved a more effective protection than safety valves and other protective devices common on natural-circulation boilers.

10 It is essential that the application of a unit of this character be carefully considered, since reduction in weight and space requirements can only be obtained through increase in auxiliary power and reduction of plant efficiency, especially at high loads. In certain applications the problem is simple, since the space requirements are definitely fixed. However, where space is available it is generally more economical to use a larger unit, improve boiler efficiency, and reduce auxiliary power.

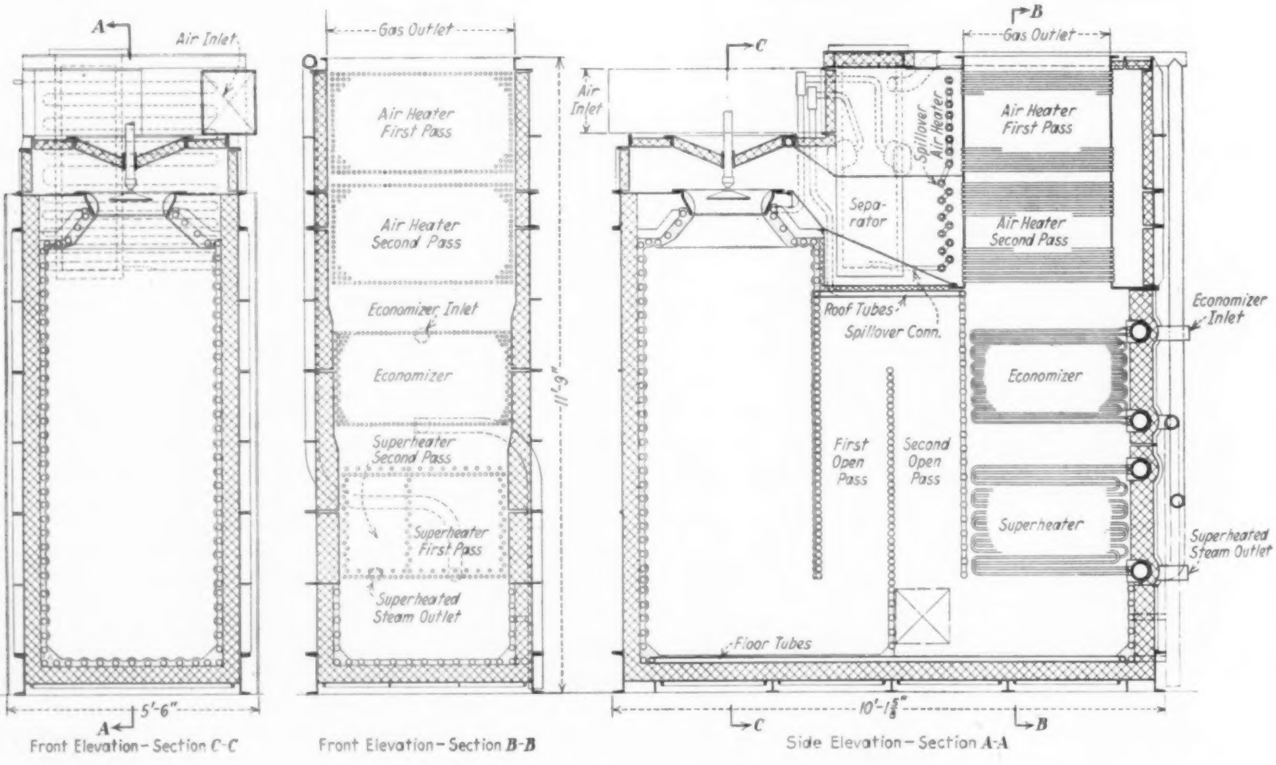


FIG. 16 VERTICALLY FIRED, OPEN-PASS STEAMOTIVE BOILER

CORROSION-RESISTANT METALS

Introductory Paper to a Symposium on Their Use in the Design of Machinery and Equipment

By F. N. SPELLER

DEPARTMENT OF METALLURGY AND RESEARCH, NATIONAL TUBE COMPANY, PITTSBURGH, PA.

FOR MANY YEARS metal corrosion has been recognized as a major problem of world-wide importance. This is not only on account of the great wastage involved, but also because of the limited services for several commercial metals, particularly iron and steel, that otherwise have a wide range of desirable physical properties.

Present interest in this subject is illustrated by the avalanche of symposiums that were scheduled for this year, which include:

- American Society for Testing Materials, on High-Strength Constructional Metals, Pittsburgh, Pa., March, 1936.
- Chemical Engineering Congress of the World Power Conference, London, England, June, 1936.
- American Chemical Society, on New Metals and Alloys, Pittsburgh, Pa., September, 1936.
- American Society of Civil Engineers, on Steel and Light-Weight Alloys, Pittsburgh, Pa., October, 1936.
- The American Society of Mechanical Engineers, on Corrosion-Resistant Metals in Design of Machinery and Equipment, New York, N. Y., December, 1936.

PAPERS COMPRISING THE SYMPOSIUM ON CORROSION-RESISTANT METALS IN THIS ISSUE

The tonnage of steel produced is about eighteen times that of all other metals so we shall refer to that metal in particular in discussing this problem. It has been estimated[1] that nearly one billion tons of steel are in use today in this country. The annual cost of maintenance, protection, and partial replacement of such a large quantity of metal is certainly a substantial figure, even without reference to consequential losses, and regardless of whether it is estimated at thirty cents or one dollar per ton, and the latter figure is probably a closer estimate. This rather conservative appraisal of the annual losses due to corrosion serves to illustrate the economic importance of the problem.

Several of the nonferrous metals play an important part in widening the application of steel, either by alloying, or plating, or in some instances by veneering, to obtain better resistance under certain conditions of exposure.

The production of low-cost higher-strength steels in lighter sections for transportation reconstruction and other structural purposes necessitated reduction in the corrosion rate. Fortunately, this was accomplished, in the case of metals subject to atmospheric corrosion, by the proper blending of small amounts of alloying elements such as chromium, copper, nickel, silicon, or phosphorus in steel.

At least one of these low-alloy higher-tensile steels shows two or three times the resistance to attack in water compared with carbon steel. This is encouraging in view of the fact, demonstrated by many extensive tests during the past 25 years, that no material difference was found in the rate of corrosion between any of the well-known commercial types of ferrous metals when used in water or in soils. In corrosive soils, where local electrolytic conditions predominate, the metal-corrosion problem is much more difficult, and at present it is necessary to resort to protective coatings or cathodic protection by counter electric current impressed on the metal.

About a decade ago the number of metals available for use in the chemical industry was comparatively limited. New developments in chemical processes on a large scale created a demand for new metals or alloys suitable for high and low temperatures and resistant to many types of severe corrosion and scaling. Such metals usually have to be capable of being forged, cast, or welded with facility. Many new metals and alloys, ferrous and nonferrous, have been developed recently for such service as well as for bearings, antigalling joints, and many other purposes, and these have been responsible in a large measure for the remarkable progress in certain industries during recent years. For example, consider the application of modern alloy steels in the production and refining of petroleum and what improving the quality and lowering the cost of petroleum products have done for other industries.[2]

Two groups of factors are involved in corrosion; those associ-

[1] American Iron and Steel Institute, *Iron Age*, vol. 137, April 2, 1936, p. 71.

Contributed to the Symposium on Corrosion-Resistant Metals in Design of Machinery and Equipment by the Iron and Steel Division for presentation at the Annual Meeting, New York, N. Y., November 30 to December 4, 1936, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

[2] See papers and discussions on this subject presented at the symposium of American Chemical Society, and published in *Industrial and Engineering Chemistry*, December, 1936.

ated with the metal and those associated with the environment. The essential points of the process or mechanism of corrosion of metals may be explained by the following facts:

The common metals (for example, iron, nickel, chromium, and copper) are relatively unstable with respect to their environment. They have been won from their ores by expenditure of considerable energy and attempt to revert with a decrease in free energy of the system to the more stable combinations (oxides, carbonates, etc.) in which form they are found in nature.

The mechanism of corrosion involves the surface chemistry of metals. The reaction of the metal with its environment may be by direct chemical union, as in the case of oxidation or scaling at elevated temperatures, or by more complicated reactions when the metal is in contact with an electrolyte, such as water, or an aqueous solution.

Considering the most common types of corrosion of metals, which occur only in the presence of liquid water, essentially there are two main steps in this interaction. The first is the initial *tendency* of the metal to enter solution. The driving force is referred to as the solution pressure of the corroding metal or the potential between adjacent parts of the metal surface. The initial corrosion is also governed by the metal composition and its structural homogeneity, surface finish, inherent power to form surface films, local strain, and overvoltage of hydrogen deposited on the metal. The second may include several reactions that determine the *rate* of deterioration and, therefore, the useful life of the metal.

In the case of iron and many of the commonly used metals, the initial rate of solution is likely to be quite rapid, and, if this is not opposed, the life of these metals in such cases would be relatively very short. Fortunately, this tendency of metals to dissolve in water is resisted by natural layers or barriers of corrosion products (solid, liquid, or gaseous) that retard and sometimes stop the reaction before any material damage is done. These protective layers consist mainly of films (sometimes invisible) or thicker corrosion deposits.

A number of factors having to do with the secondary reactions play an important part in the building up or breaking down of these metal surface layers. The principal ones are: (1) acidity; (2) free oxygen; (3) flow velocity; (4) temperature; (5) cyclic stress; (6) materials in the metal or environment that assist in forming the protective layer; and (7) various contact effects.

Some of these factors affect the average rate of attack and others the *distribution* of corrosion, and all are likely to have an important influence on the life of the metal. Localized attack is, of course, important in the case of pipe or containers, as pitting may cause perforation of the metal long before it has lost much in weight.

In the presence of water, corrosion is accompanied and promoted by electrochemical reactions. That is, the metal enters the solution at certain anodic areas and an equivalent amount of hydrogen is plated out at adjacent cathodic areas. The anodic and cathodic reactions occur simultaneously. Free oxygen or oxidizing compounds accelerate attack on the metal by combining with the polarizing film of hydrogen. If oxygen is not available for this purpose, corrosion is reduced to a negligible amount in water that is alkaline or only slightly acid, but if the acidity is sufficient to cause evolution of gaseous hydrogen, the way is open for more metal to dissolve. If the anodic and cathodic areas are relatively small, corrosion will be fairly uniformly distributed. On the other hand, the attack becomes more localized in the form of pits as the ratio of anodic to cathodic areas is reduced and as the electrical conductivity of water increases. It follows that attack on the metal would be more uniformly distributed when the ratio of anodic to cathodic area is increased, and the electrical conductivity of the solution is decreased.

Pitting is promoted by any local increase in potential. This is due mainly to contact with dissimilar metals or other material on the surface, such as mill scale on steel, concentration or solution cells, or internal strain. Differences in oxygen concentration in water solution have proved to be the most common cause of pitting, the area exposed to the solution that is *highest* in oxygen being cathodic to parts exposed to lower oxygen concentration. In other words, corrosion occurs more rapidly where the solution next to the metal is *deficient* in oxygen. Deposits of corrosion products, cracks or angles in the structure, or solid foreign matter of almost any kind that interferes with diffusion are likely to result in variations in oxygen concentration sufficient to form an active concentration cell at such spots on the metal. Variations in concentration of solutions or solutions of different materials set up solution cells with the same result. It is, therefore, important in designing structures subject to corrosion to keep the metal surface as clean as possible. Dust particles in the air, especially when a little sulphur dioxide is also present, accelerate electrolytic action when the relative humidity is in excess of 70 per cent.

Variable stresses far below the fatigue limit in air, when accompanied by water corrosion, may cause early failure. The endurance limit of carbon or alloy steels has been reduced from half the tensile strength to as low as 12,000 lb per sq in. under such conditions. Special precautions should be taken to protect parts from corrosion when under high cyclic stresses.

Sometimes the attack is directed along grain boundaries or other lines of weakness in the metal, as in dezincification of brass, graphitization of cast iron, or the grain-boundary attack sometimes found in unstabilized 18–8 chromium-nickel steel.

The factors referred to and many others rarely act independently; the effect of each is modified by others. For example, velocity of flow increases oxygen depolarization on iron up to a certain point above which it promotes the building up of ferric protective films and corrosion decreases. However, one or two factors usually control the rate of corrosion.[3]

The rate of corrosion may be considered as analogous to flow of water under pressure in a pipe line in which there are several different valves. The flow may, of course, be controlled by partly closing one or more of these valves. For example, corrosion is sometimes encountered in gasoline pipe lines, especially near the inlet. Water and oxygen are slightly soluble in gasoline. The water condenses out on the inside wall of the pipe when the gasoline is cooled, for instance, by contact of the pipe with the ground. Plenty of free oxygen is available in the gasoline to keep the reaction going. In this case corrosion may be brought under control by dehydrating the gasoline, removing the free oxygen, or by injecting a soluble inhibitor that will be taken up by the condensed water and build up a protective film. However, only one of these expedients need be used to prevent the metal from being seriously damaged.

The corrosion problem is now recognized not as a single one, but rather as a group of problems complicated by many variables, the resultant of which determines the rate of attack. Corrosion types may be classified in various ways, but it seems logical to group them according to the common controlling

[3] Those interested in details of these corrosive reactions may refer to "The Corrosion of Metals," by Ulick R. Evans, Arnold and Co., London, 1926; "Corrosion Resistance of Metals and Alloys," by McKay and Worthington, Reinhold Publishing Corp., New York, N. Y., 1936; "Corrosion—Causes and Prevention," by F. N. Speller, McGraw-Hill Book Co., New York, N. Y., 1936.

factors. In view of the fact that factors external to the metal usually predominate, it is convenient to classify corrosion according to the environment, and thus we may speak of it as atmospheric, underwater, soil, chemical corrosion, or electrolysis due solely to stray electric currents. In atmospheric corrosion the predominant factor is moisture; in water, oxygen concentration; in soil, electrical conductivity, total acidity, and water content. This system of classification is useful in corrosion testing and in considering the most economical means of prevention.

Most preventive measures[4] may be divided into three groups according to the principle employed: (1) Paints, lacquers, and other applied coatings; (2) treatment of environment to make it less active toward metals (for example, by the addition of soluble alkalies, chromates, phosphates, or silicates to water to assist in forming a natural protective layer on the metal); and (3) the use of metals that have the power to form self-healing protective films with the particular environment under consideration. As the purpose of the two latter principles is to build a resistant film by reaction between the metal and the environment, it is obviously necessary to make a thorough analysis of all the surrounding factors before attempting to select or develop a metal that will react favorably and protect itself for a reasonable time. It is important to remember that in corrosion problems we are dealing not with the real metal surface but with metal-surface films. Natural protective layers are more easily formed in air than in solutions or in soils. For instance, the addition of 0.20 per cent copper will double the resistance of steel in industrial air at an increase in cost of about $3 per ton, but copper steel shows practically no advantage when submerged in domestic or sea water.

Where chemical solutions are involved each case is usually a separate problem and no metal has been found that is proof against all conditions without the aid of some additional protective coating. For example, in certain soils the local electrolytic action of moist soil particles sets up such a strong difference of potential that it sometimes breaks down the protective film on copper, 18–8 chromium-nickel steel, or 27 per cent chromium steel. There are exceptional cases, but as a rule the difference between all the common types of ferrous metals, including copper steel and 5 per cent chromium steel, is not material in soils, as shown in the Bureau of Standards' exposure tests.[5]

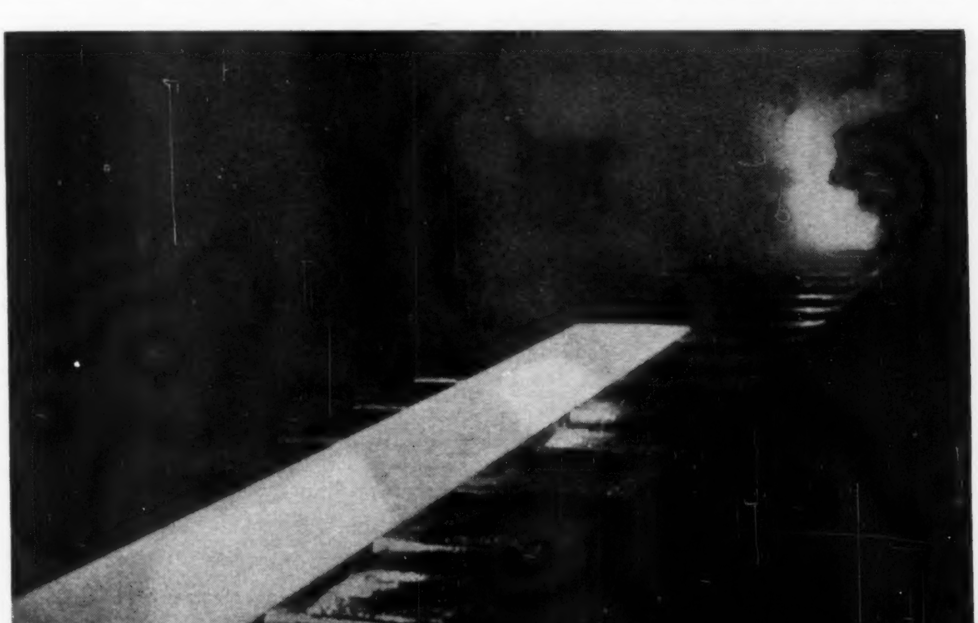
SUMMARY

It does not seem likely that we shall find one metal or one general remedy for all kinds of corrosion. The metal and environment must be mated so as to live together peaceably, at least until the owner gets a reasonable return on his investment. This is essentially an economic problem, the answer to which may be to let the structure alone and recondition when necessary, as is often the practice in buried pipe lines; to apply a coating of a more resistant material; to condition the environment so that it will be less active; or to select the metal or alloy best adapted to the particular conditions of service at the lowest consistent cost. Structural design, regulation of environment, and care of metals are important factors in their life. It should be remembered that metals are, in a way, quite like human beings; although they are susceptible to unfavorable environment, their resistance can be built up by inoculating them with alloying elements and by keeping their surfaces reasonably clean and free from foreign deposits. As the useful life of any metal is determined mainly by the film-building properties of both the environment and the metal, and as metals have to live under so many conditions of service, it is extremely improbable that any one metal can be made at reasonable cost that will meet all the common conditions of service. The problem of the engineer, therefore, is to select the metal that will best serve any specific purpose at the lowest *ultimate* cost. Too much attention may be given to *first* cost.

In this introduction I have been requested to discuss in simple terms the problem of corrosion in general. Specific details in regard to recent developments of various metals used for industrial purposes have been avoided, as these will be covered by the authors of special papers that follow.

[4] "Influence of Protective Layers on the Life of Metals," by F. N. Speller, MECHANICAL ENGINEERING, vol. 57, no. 5, 1935, pp. 355–360.

[5] U. S. Bureau of Standards Research Paper No. 883, May, 1936.



Gerald Young

ALUMINUM *and* ITS ALLOYS

In the Design of Corrosion-Resistant Machinery and Equipment

By E. H. DIX, JR., and R. B. MEARS

ALUMINUM RESEARCH LABORATORIES, NEW KENSINGTON, PA.

THE IMPORTANCE of the choice of the most economical alloys for machinery and equipment subjected to corrosive conditions is being emphasized by the interest that all of the major technical societies are showing in this subject. During the past decade many new corrosion-resistant alloys have been developed and placed on the market. Faced with this long list of new materials upon which there is only a limited amount of service experience, some of which has not borne out the optimistic claims of the manufacturers, the designing engineer finds himself in a quandary in selecting materials. Later, the operating engineer is not always fully informed concerning the treatment which these new materials require for best service life. Formerly, if long life under corrosive conditions was desired, the engineer turned to a few well-known nonferrous alloys. If a cheaper construction was desired, ordinary steel was used and either properly protected or allowed to rust away, depending upon the whims of the operator.

The term "corrosion-resistant" is purely relative. No one metal or material is entirely resistant to all conditions to which it may be subjected. Whether or not a material may be considered corrosion-resistant under a given set of circumstances depends upon what is expected of it; that is, is it expected to

1 Maintain its original surface appearance without tarnishing, staining, or discoloring surrounding parts of the structure.

2 Produce no deleterious effect upon contact with the product which is being handled.

3 Resist perforation so that leaks will not occur.

4 Maintain its original mechanical properties so that the structure will not be weakened.

Of course, sometimes two or more of these factors enter into the situation. In the case of the last two criteria it must be remembered that, since corrosion is largely a surface phenomenon, the thickness of the part is important; which means that higher resistance to corrosion in such applications is demanded of thin sheet than of castings and forgings, which are usually of much greater thickness.

"COOKBOOK DATA" DANGEROUS

It is thus evident that the suitability of any alloy for a given application depends so much upon the specific circumstances surrounding that application that the presentation of data in "cookbook" form is not only inadequate but may prove extremely hazardous. In this paper, therefore, an attempt will be made merely to describe the commercially useful corrosion-resistant aluminum alloys and their particular characteristics which fit them for machinery and equipment subjected to corrosive conditions, and to make only broad generalizations as to the type of service for which they are best fitted. Detailed knowledge of the specific conditions of service is required before a recommendation can be attempted, and it is generally preferable to conduct pilot tests before going into a large installation.

As a class, most commercial aluminum alloys are properly considered corrosion-resistant; that is, they resist most corrosive conditions better than many other metals. In addition, they offer the important advantage of not staining adjacent parts and, furthermore, their salts are colorless and not toxic to man or beast (1).[1]

FILM PROTECTION

The resistance to corrosion of aluminum and aluminum alloys is largely the result of their film-forming characteristics. The ever-present aluminum-oxide film is protective under a great variety of conditions. Full recognition of this important characteristic will aid greatly in the intelligent use and maintenance of aluminum equipment employed in corrosive environments. Under most conditions, this film is self-repairing provided sufficient oxygen is present. Periodic cleaning, if necessary, especially with a mildly abrasive cleaner, will greatly aid in maintaining a uniformly resistant film. Thicker films may be produced artificially by electrolytic treatments in which the aluminum is made the anode in an aqueous solution, (2) hence the term "anodic coating." The patented process which is most generally employed in this country is known as the "Alumilite" process (3).

THE PRINCIPLE OF ALCLAD PRODUCTS

In applications requiring the use of relatively thin sheet under corrosive conditions where maintenance of original mechanical properties or resistance to destructive perforation is required, Alclad products are recommended. In principle, these products have corrosion-resistant surface layers of aluminum or an alloy whose solution potential is such that it will electrolytically protect the underlying core. Thus, corrosion cannot penetrate beyond the interface between the surface layer and the core until most of the surface layer is removed. Because of this action any corrosion which occurs is shallow and spreads out over the surface instead of penetrating into the core. In the case of Alclad 17S-T and Alclad 24S-T, used principally in aircraft, this means that the mechanical strength of the high-strength alloy core is not impaired; whereas in an Alclad common alloy used as a container of any sort, it means that deep pitting, which might result in perforation, will not occur. It is obvious from the discussion of this principle that these products have no particular advantage in applications where surface appearance is the determining factor.

EFFECT OF ALLOYING ELEMENTS

Generally speaking, the excellent resistance of pure aluminum to corrosion is not improved by alloying elements. Of the

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[1] Numbers in parentheses refer to Bibliography at the end of the paper.

principal alloying elements used to increase the strength and hardness, manganese, chromium, and magnesium are without deleterious effect on the resistance to corrosion; whereas silicon, zinc, nickel, and copper have a somewhat adverse effect, depending on the alloy and its microstructural condition. Under some conditions, magnesium and chromium may improve the resistance to corrosion by enhancing the self-repairing nature of the surface film. Of course, through interaction, combinations of elements have beneficial effects, for instance, magnesium and silicon when combined in the exact ratio of the compound Mg_2Si form the active phase in the most important heat-treatable, corrosion-resistant, wrought aluminum alloy. Obviously, the detrimental effect of some of the alloying constituents, such as copper, is the result of the difference in solution potential between aluminum and the constituents formed with these alloying elements. The distribution of these constituents, as affected by heat-treatment, is important.

TABLE 1 TYPICAL COMPOSITIONS[a] OF WROUGHT ALUMINUM ALLOYS

Alloy designation	Copper	Silicon	Manganese	Magnesium	Chromium	Nickel	Zinc	Molybdenum
2S	...	...	...	...	...	...	...	...
3S	...	...	1.25	...	...	...	...	...
4S	..	...	1.25	1.0	...	...	...	...
14S[b]	4.4	0.8	0.75	0.35	...	...	...	...
17S	4.0	...	0.5	0.5	...	...	...	...
24S	4.2	...	0.5	1.5	...	...	...	...
25S[b]	4.5	0.8	0.8	...	...	...	...	...
51S[b]	...	1.0	...	0.6	...	...	...	...
A51S[b]	...	1.0	...	0.6	0.25	...	...	...
52S	...	...	...	2.5	0.25	...	...	...
53S	...	0.7	...	1.25	0.25	...	...	...
Nicral A	0.5	0.3	0.16	0.50[c]	0.18	1.0	0.2	0.16
Nicral B	0.25	0.3	0.08	0.50[c]	0.09	0.5	0.2	0.08
Nicral FM	0.25	0.5	0.08	0.75[c]	0.09	0.5	0.2	0.08
Nicral X	1.0	0.5	0.16	0.75[c]	0.18	1.0	1.0	0.16

[a] The compositions of some of these alloys are patented.
[b] Principally used for forgings.
[c] The addition of magnesium to nonheat-treated alloys is indicated by the letter M to the alloy letter. Whenever the alloy is in the heat-treated condition, it is understood that magnesium is present.

TABLE 2 TYPICAL COMPOSITIONS[a] OF SAND-CASTING ALLOYS

Alloy designation	Copper	Iron	Silicon	Zinc	Magnesium
12	8.0	...	...	...	...
43	...	...	5.0	...	...
112	7.5	1.2	...	1.5	...
195	4.0	...	...	...	...
212	8.0	1.0	1.2	...	...
214	...	...	...	...	3.75
216	...	...	...	...	6.0
220	...	...	...	...	10.0
355	1.25	...	5.0	...	0.5
356	...	...	7.0	...	0.3

[a] The compositions of some of these alloys are patented.

TABLE 3 TYPICAL COMPOSITION[a] OF PERMANENT-MOLD AND DIE-CASTING ALLOYS

Alloy designation	Copper	Iron	Silicon	Magnesium	Nickel
		Permanent-mold alloys			
43	...	...	5.0	...	...
B113	7.5	1.2	1.5	...	...
122	10.0	1.2	...	0.2	...
A132	0.8	0.8	12.0	1.0	2.5
142	4.0	...	...	1.2	2.0
B214	...	...	1.75	3.75	...
		Die-casting alloys			
13	...	...	12.0	...	...
81	8.0	...	3.0	...	...
85	4.0	...	5.0	...	...

[a] The compositions of many of these alloys are patented.

HEAT-TREATMENT

A lengthy description of the metallurgy of the various alloys would be out of place in this paper. However, since many of the alloys, both wrought and cast, obtain their desirable mechanical properties through heat-treatment, a brief discussion of this process as applied to aluminum alloys seems justified. Heat-treatment is possible in most of those alloys in which the alloying constituents have a greater solid solubility at elevated temperatures than at room temperature, hence by heating these alloys just under the beginning of the melting range it is possible to put the soluble elements in solution. A rapid quench brings this microstructural condition to room temperature. This process is known as a solution heat-treatment. After quenching, some aging takes place at room temperature, but this is generally of relatively small magnitude except in the case of the well-known duralumin-type alloys containing both copper and magnesium (17S and 24S). In these alloys, natural aging, caused by precipitation in highly dispersed form, takes place at room temperature and is substantially complete in about four days; thus, this room-temperature aging produces the final heat-treated temper "T." However, in most of the other alloys the room-temperature-aged temper is designated "W" for wrought materials or "T4" castings. The maximum strength and hardness are obtained only by a second heat-treatment, known as "artificial aging" or "precipitation" treatment, which is carried out in the temperature range 250 to 350 F. In the wrought alloys this is indicated by the suffix "T." The duralumin-type alloys (17S and 24S) are most workable immediately after quenching and are sometimes formed in this condition when the required operations are difficult. The W temper of the other wrought alloys also offers ready workability; the subsequent low-temperature aging produces no undesirable distortion.

CLASSIFICATION OF ALLOYS

The chemical composition of the more corrosion-resistant alloys and typical mechanical properties in various forms are given in Tables 1 to 8. These tables do not include all of the commercially available aluminum alloys but have been selected with special reference to high resistance to corrosion. For data covering additional alloys, the reader should refer to the literature (4, 5, 6, 7, 8). Some brief generalizations concerning the various alloy compositions may be helpful.

WROUGHT COMMON ALLOYS

The wrought alloys may be grouped in two main divisions: (1) Common alloys or those that cannot be heat-treated, and (2) alloys susceptible to heat-treatment. In general, the alloys of the first group are more resistant to corrosion but they possess only moderate strength. In forms which can be cold-worked as, for instance, cold-rolled sheet and plate, a variety of tempers having different combinations of strength and work-

TABLE 4 TYPICAL MECHANICAL PROPERTIES OF WROUGHT ALUMINUM ALLOYS[a]

Alloy	Temper[f]	Tension: Yield strength,[b] lb per sq in.	Tension: Ultimate strength, lb per sq in.	Tension: Elongation[c] in 2 in., per cent, sheet specs. 0.064 in. thick	Hardness: Brinell, 500 kg, 10-mm ball	Shear: Shearing strength,[d] lb per sq in.	Fatigue: Endurance limit,[e] lb per sq in.
2S	O	4,000	13,000	35	23	9,500	5,000
2S	1/2H	14,000	17,000	9	32	11,000	7,000
2S	H	21,000	24,000	5	44	13,000	8,500
3S	O	5,000	16,000	30	28	11,000	7,000
3S	1/2H	18,000	21,000	8	40	14,000	9,000
3S	H	25,000	29,000	4	55	16,000	10,000
4S	O	10,000	26,000	20	45	16,000	14,000
4S	1/2H	27,000	33,000	9	63	18,000	15,000
4S	H	34,000	40,000	5	77	21,000	16,000
17S	T	35,000	58,000	20	100	35,000	15,000
17S	RT	46,000	61,000	13	110	36,000	....
Alclad 17S	T	32,000	55,000	18	...	32,000	....
24S	T	43,000	65,000	20	105	40,000	14,000
24S	RT	53,000	68,000	13	116	41,000	14,500
Alclad 24S	T	40,000	60,000	18	...	39,000	....
51S	W	20,000	35,000	24	64	24,000	10,500
51S	T	38,000	48,000	14	95	30,000	10,500
52S	O	14,000	29,000	25	45	18,000	17,000
52S	1/2H	29,000	37,000	10	67	21,000	19,000
52S	H	36,000	41,000	7	85	24,000	20,500
53S	O	7,000	16,000	25	26	11,000	7,500
53S	W	20,000	33,000	22	65	22,000	10,000
53S	T	32,000	38,000	14	80	26,000	11,000
Nicral A	O	8,500	21,000	20	...	....	....
Nicral A	CO	15,000	26,000	19	...	....	....
Nicral A	D2012	40,000	46,000	9	...	....	....
Nicral B	O	7,000	18,000	26	...	....	....
Nicral B	2	20,000	21,000	6	...	....	....
Nicral FM	O9	28,000	34,000	14	...	....	....
Nicral X	DO18	41,000	51,000	16	...	....	....

[a] Young's modulus of elasticity is approximately 10,300,000 lb per sq in.
[b] Stress which produces a permanent set of 0.2 per cent of the initial gage length. (A.S.T.M. Specification for Methods of Tension Testing, E 8-33.)
[c] Elongation values vary with the form and size of tension-test specimen. Thin sheet has somewhat lower elongation than values for 0.064-in. sheet shown in table. Thicker material, from which standard round tension-test specimens (0.505-in. diam) are tested, may have lower elongation because of the effect of commercial flattening operations on this property.
[d] Single-shear strength values obtained from double-shear tests.
[e] Based on withstanding 500,000,000 cycles of completely reversed stress, using the R. R. Moore type of machine and specimen.
[f] O = fully annealed; H = fully hardened by cold work; 1/2 H = intermediate cold worked temper; W = solution heat treatment only; T = solution heat treatment, followed by precipitation; RT = solution treatment, followed by precipitation, followed by cold work.

TABLE 5 TYPICAL MECHANICAL PROPERTIES OF SAND-CASTING ALLOYS[a]

Alloy	Tension[c]: Yield strength[b] (set = 0.2%), lb per sq in.	Tension[c]: Ultimate strength, lb per sq in.	Tension[c]: Elongation in 2 in., per cent	Compression[f]: Yield strength (set = 0.2%), lb per sq in.	Compression[f]: Ultimate strength, lb per sq in.	Hardness Brinell, 500 kg, 10-mm ball	Shear Shearing strength,[d] lb per sq in.	Fatigue Endurance limit,[e] lb per sq in.	Density lb per cu in.
12	14,000	22,000	2.0	16,000	38,000	65	20,000	7,500	0.102
43	9,000	19,000	4.0	9,000	25,000	40	15,000	6,500	0.096
112	14,000	22,000	2.0	24,000	44,000	70	20,000	8,500	0.103
195-T4	16,000	31,000	8.0	27,000	43,000	65	28,000	6,000	0.100
195-T6	22,000	36,000	4.0	29,000	48,000	80	30,000	6,500	0.100
212	14,000	22,000	2.0	16,000	38,000	65	20,000	7,500	0.102
214	12,000	25,000	9.0	12,000	50,000	50	19,000	5,500	0.095
220-T4	25,000	44,000	13.0	23,500	72,500	75	33,500	7,000	0.092
355-T4	20,000	30,000	5.0	25,000	65,000	60	30,000	...	0.097
355-T6	27,000	35,000	3.0	29,000	68,000	80	30,000	...	0.097
356-T4	16,000	28,000	6.0	16,000	46,000	55	22,000	...	0.095
356-T6	22,000	32,000	4.0	21,000	48,000	70	23,000	8,000	0.095

[a] Young's modulus of elasticity is approximately 10,300,000 pounds per square inch.
[b] Stress which produces a permanent set of 0.2 per cent of the initial gage length. (A.S.T.M. Specification for Methods of Tension Testing, E 8-33.)
[c] Tension values determined from standard half-inch diameter tensile-test specimens individually cast in green-sand molds and tested without machining the surface. See page 51 "Design of Aluminum-Alloy Castings."
[d] Single-shear strength values obtained from double-shear tests.
[e] Based on withstanding 500,000,000 cycles of completely reversed stress, using the R. R. Moore type of machine and specimen.
[f] Results of tests on specimens having an l/r ratio of 16 to 20. All specimens failed by lateral bending.

ability, indicated by O (annealed), 1/4 H, 1/2 H, 3/4 H, H (full hard), are available. Attention is directed to the relative ease with which aluminum alloys can be economically extruded into very complicated sections of accurate dimensions. In extruded form the common alloys have a temper approximately equivalent to 1/4 H. The difference in resistance to corrosion of the various common wrought alloys is generally not great enough to be a deciding factor in their selection, with the exception that 52S possesses exceptionally high resistance to sea water and salty atmospheres. This higher resistance to

TABLE 6 MECHANICAL PROPERTIES[a] OF PERMANENT-MOLD CASTINGS[c]

Alloy	Ultimate strength, lb per sq in.	Elongation in 2 in., per cent	Brinell hardness,[b] 500-kg load, 10-mm ball	Typical density, lb per cu in.
43	21,000	2.5	45–55	0.097
B113	24,000	...	70–90	0.103
122–T52	27,000	...	95–125	0.104
122–T65	38,000	...	125–150	0.104
A132–T4	30,000	...	90–120	0.097
142	26,000	...	90–115	0.100
B214	22,000	2.0	50–65	...

[a] Properties obtained from standard $^1/_2$-in. diameter test specimens, individually cast in a permanent mold, and tested without machining off the surface. The heat-treatment and the chill casting of many of these alloys are patented.

[b] Brinell limits obtained from tests on commercial castings. For 122 and 142 alloys, values apply to readings taken on piston head $^1/_2$ in. from edge and $^1/_2$ in. from gate on pistons having thickness of head up to $^1/_2$ in. Thicker castings, castings poured with sand core or poured in sand give lower values, the maximum decrease being about 20.

[c] Young's modulus of elasticity is approximately 10,300,000 lb per sq in.

TABLE 7 TYPICAL MECHANICAL PROPERTIES[a] OF DIE-CASTING ALLOYS[b]

Alloy	Ultimate strength, lb per sq in.	Elongation in 2 in., per cent
13	33,000	1.3
81	32,000	1.3
85	35,000	3.0

[a] Tensile properties are averages of values obtained from A.S.T.M. standard round die-cast specimen, $^1/_4$ in. in diameter. Brinell hardness obtained from A.S.T.M. standard flat die-cast test specimen, $^1/_8$ in. thick, using 125-kg load and 5-mm ball.

[b] Young's modulus of elasticity for all alloys is approximately 10,300,000 lb per sq in.

The chill casting of many of these alloys is patented.

corrosion is obtained, in part, through rigid control of the impurities.

WROUGHT HEAT-TREATABLE ALLOYS

The heat-treatable wrought aluminum alloys of highest strength contain copper as a principal alloying element and their resistance to corrosion is definitely lower than that of the common alloys, but still quite adequate for many purposes. For those alloys having both a W and a T temper, generally the as-quenched, or W, temper, is the more resistant. The alloy 53S, containing no copper except as an impurity held to the lowest practical minimum, provides a material susceptible to heat-treatment which, in either the W or T temper, has the same order of resistance to corrosion as the common alloys. This high resistance to corrosion is obtained by strict control of a balanced composition. This alloy is particularly useful in the extruded form and, by heat-treatment, considerably higher strengths can be obtained than are possible in the extruded common alloys.

COMMERCIAL AVAILABILITY

In the case of flat sheet the maximum commercial width varies from 30 in. for a thickness of 0.005 in. to 102 in. for thicknesses from 0.093 to 0.249 in. The available length also varies with the thickness from 8 ft to 24 ft or even longer for some classes of material.

Plate is supplied in thickness up to $2^1/_2$ or 3 in. and in widths up to 120 or 130 in. depending upon the alloy. These maximum dimensions are subject to the limitation that the maximum weight of an individual plate is 2000 lb.

Tubing in a wide range of sizes from about $^1/_{16}$ to over 11 in. in outside diameter is also manufactured, the range of wall thickness varying with the diameter.

In special cases these limiting sizes and gages can sometimes be materially exceeded. In addition, forms such as rod, bar, wire, structural shapes, bottle seals, foil, screw-machine products, and light-reflector sheets are available in some of the alloys listed here or in other alloys not mentioned in the tables.

PROTECTIVE METHODS AVAILABLE, IF REQUIRED

The high strength-weight ratio of the heat-treated aluminum-copper alloys often justifies the use of these materials under corrosive conditions where protection is required. Adequate protective methods have been developed to meet a wide variety of corrosive conditions. Several of the less corrosion-resistant aluminum alloys are used satisfactorily to resist normal atmospheric corrosion. This is particularly true in the case of forgings where relatively thick sections are employed; for instance, aircraft propeller blades of 25S-T have been used successfully for a great many years without a single reported case of difficulty from corrosion. The light weight and the good mechanical properties of 53S-T dictate its use in high-speed centrifugal buckets used in the rayon industry, even though the metal must be protected against the action of some of the more concentrated solutions of sulphuric acid with which it comes in contact.

CASTING ALLOYS

The casting alloys also may be divided into two groups, depending upon whether or not they are susceptible to heat-treatment. Again, high strengths are obtainable only in heat-treated alloys but, in this case, one of the highest strength alloys, 220-T4, is also one of the most resistant to many corrosive conditions. This alloy represents the highest combination of strength and shock resistance obtainable in cast aluminum alloys. The alloys of lower magnesium content—214 and 216—represent the most corrosion-resistant casting alloys available. They are particularly advantageous in resisting sea water and salt atmospheres. The aluminum-silicon alloys are somewhat less resistant, particularly to salt conditions. However, the alloy 43, containing 5 per cent silicon, has been used in architectural applications (spandrels and the like) for many years in all parts of the country, with eminently satisfactory results. For maximum resistance to corrosion it is necessary to maintain a low value for copper as an impurity in this alloy. The heat-treatable alloy 356, in the as-quenched temper (T4), has about the same resistance to corrosion as 43 alloy. Its resistance is lowered somewhat by artificial aging.

The aluminum-magnesium alloys are difficult to die-cast satisfactorily, especially in intricate shapes. The die-casting alloy No. 13 offers satisfactory resistance to corrosion for a great variety of applications. Where higher resistance to corrosion is required for special purposes, a controlled purity grade of No. 13 alloy is available.

FORMING

A detailed discussion of methods of fabrication of aluminum alloys would be out of place in this paper. For this reason, only those practices having an effect on the resistance to corrosion will be discussed. Some indication of the formability of the various wrought alloys may be obtained from the data given in Table 8. Hot-forming, so common in steel fabrication, introduces difficulties in the aluminum alloys. In the case of the wrought alloys of intermediate or hard-rolled

TABLE 8 AVAILABLE COMMERCIAL FORMS OF WROUGHT ALLOYS

Alloy	Sheet	Plate	Wire	Rod and bar	Rolled shapes	Extruded shapes	Tubing and pipe	Rivets	Forgings
2S	x	x	x	x	....	x	x	x	....
3S	x	x	x	x	....	x	x	x	....
4S	x	x	....	....	....	....	....	....	....
14S	....	....	....	....	....	....	....	....	x
17S	x	x	x	x	x	x	x	x	x
Alclad 17S	x	....	....	....	....	....	....	....	....
24S	x	....	....	....	....	x	x	....	....
Alclad 24S	x	....	....	....	....	....	....	....	....
25S	....	....	....	....	....	....	....	....	x
51S	x	x	x	x	....	x	x	....	....
A51S	....	....	....	....	....	....	....	....	x
52S	x	x	x	x	x	....	x	....	....
53S	x	x	x	x	....	x	x	x	x
Nicral A	x	x	x	x	....	x	x	x	....
Nicral B	x	x	x	x	....	x	x	....	....
Nicral X	x	x	x	x	....	x	x	....	....
Nicral FM	....	....	....	....	....	x	....	....	....

TABLE 9 SUMMARY OF THE EFFECT OF VARIOUS SUBSTANCES ON ALUMINUM AND ITS ALLOYS

1 *Atmospheric Exposure:* Pure aluminum or the resistant aluminum alloys are little affected by even rather long periods of exposure to the atmosphere in a wide range of different locations. If it is desirable that a bright surface be maintained, the alloy should generally be Alumilited.

2 *Marine Exposures:* The Alclad aluminum alloys and 52S and 53S are highly resistant to sea water or salt spray.

3 *Neutral Salt Solutions:* Aluminum and many of its alloys are little affected by solutions of most neutral salts. The halogen salts are more active so that special precautions must sometimes be taken if aluminum is to be used in direct contact with their solutions.

4 *Alkaline-Salt Solutions:* Aluminum is generally attacked by alkaline salt-solutions. This attack can be inhibited by the addition of sodium silicate.

5 *Acid-Salt Solutions:* Solutions of salts of the heavy metals having an acid reaction are generally quite corrosive to aluminum. This is especially true for the halogen salts. Oxidizing acid salts, such as potassium dichromate, generally do not attack aluminum.

6 *Mineral Acids:* Either very dilute or very concentrated nitric or sulphuric acids have little effect on aluminum. Intermediate concentrations are quite corrosive. Sulphurous acid attacks aluminum only slowly at concentrations up to 1 normal. Boric acid has very little action on aluminum, even up to saturated solutions. However, the halogen acids are quite corrosive.

7 *Organic Acids:* Most organic acids do not have much effect on aluminum unless they are almost devoid of water. However, formic, oxalic, and mono- and tri-chlor acetic acids are rather corrosive.

8 *Alkalies:* Sodium- and potassium-hydroxide solutions readily attack aluminum at all but the lowest concentrations. Ammonium hydroxide does not seriously attack aluminum.

9 *Organic Solvents:* Aluminum is not appreciably attacked by a wide range of organic liquids. However, some, e.g., the alcohols, do attack aluminum if completely anhydrous.

10 *Gases:* Dry gases are generally inert to aluminum. Many moist gases such as ammonia and hydrogen sulphide also have little effect on aluminum while some other moist gases have slight action. Moist chlorine is decidedly corrosive.

temper, hot-forming tends to remove the strength imparted by cold-working and, of course, in the heat-treated alloys the beneficial effect of heat-treatment on strength is largely destroyed by hot-forming. Hot-forming of the common alloys has no effect on their resistance to corrosion, but hot-forming of the high-strength aluminum-copper alloys in the heat-treated condition lowers their resistance to corrosion as well as their mechanical properties. Both resistance to corrosion and properties, of course, can be restored by subsequent reheat-treatment. Certain heat-treated alloys, notably the alloy 53S–T, can be heated for forming without adverse effect on the mechanical properties or resistance to corrosion, provided the temperature does not exceed 400 F and the time is not greater than approximately one-half hour.

WELDING

Aluminum alloys can be welded by all of the usual methods but, again, consideration must be given to the effect of the heat of welding on the adjacent metal. The cold-worked common alloys are softened in the zone adjacent to the weld. In heat-treatable alloys the effect of heat-treatment is destroyed in this zone and, furthermore, the resistance to corrosion is adversely affected except that of alloy 53S and one or two others not considered in this paper. Consideration must also be given to the composition of the welding wire, since electrolytic effects may be encountered in some corrosive conditions. Welds are most easily made with 5 per cent silicon welding wire but, under conditions where the use of this alloy in contact with the alloy being welded is not advisable, rod of 2S or of the alloy itself may be employed.

RIVETING

For many applications riveted construction is satisfactorily employed; here, again, consideration must be given to the rivet alloy used in contact with various plate or sheet alloys. The readily available rivet materials are listed in Table 8. Rivets of 53S may be used in contact with any of the common alloys and Alclad materials without electrolytic action under severely corrosive conditions. In aircraft, 17S-T and A17S-T rivets are used in Alclad sheet quite satisfactorily, although under severely corrosive conditions the surface coating surrounding the rivet shows some signs of attack consequent upon its action in protecting the rivets. Soldering is not recommended for permanent use under corrosive conditions.

RESISTANCE TO ATMOSPHERIC EXPOSURE

The resistance of aluminum and its alloys to corrosion on atmospheric exposure is generally very good. In addition, what attack does occur seems to be self-stopping; that is, the rate of attack falls off with increasing time of exposure. Thus Wilson (9) has shown that, although aluminum wire lost approximately 12 per cent in tensile strength and 49 per cent in elongation in the first eight years of exposure to the London atmosphere, there was no further loss in these properties in the succeeding 15 years. Similarly, Dix (10) and Rawdon and Mutchler (11) have noted this self-stopping effect.

Since this reduction in the rate of attack is so pronounced with aluminum and its alloys, it is of special importance that material always be tested in the gage or thickness which it is desired to employ. Clearly, if thin test specimens are employed so that a relatively large percentage of the metal is attacked before the self-stopping action comes into play, erroneous conclusions regarding the behavior of thicker sections in this exposure will result.

Many studies of the effect of exposure in different outdoor locations on the various aluminum alloys have been made. Possibly the most extensive are those conducted by the American Society for Testing Materials (12) and those by the Aluminum Research Laboratories. The specimens employed in these tests were generally standard A.S.T.M. tension specimens 0.032 or 0.064 in. thick (in the case of sheet), and 0.25 or 0.505 in. in diameter for cast bars.

The locations at which specimens were exposed embrace a wide range of different types of atmospheres. They include industrial locations, such as Pittsburgh, Altoona, and New Kensington, Pa.; sea-coast exposures like Point Judith, R. I., Sandy Hook, N. J., Key West, Fla., and La Jolla, Calif.; locations which, though industrial, also include some of the characteristics of sea-coast exposures, as New York City and San Francisco; warm tropical exposures as Georgetown, British Guiana; a semi-industrial atmosphere as Rochester, N. Y., and finally, rural locations as represented by State College, Pa., and Phoenix, Ariz. Since several different tests are involved, all alloys were not exposed at all locations.

The results of tests have indicated that, for all exposures of duration up to five years to which they were subjected, specimens 0.064 in. thick of alloys such as 2S, 3S, 4S, 53S-W, 53S-T, Alclad 17S-T, Alclad 24S-T, and Alclad 24S-RT show generally small or insignificant alteration in physical properties. Evidently these materials are exceptionally resistant to atmospheric attack.

For the thinner-gage specimens (12) (0.032 in. thick), those of alloy 2S-$^1/_2$H and Alclad 17S-T exposed for three years have shown no significant change in tensile strength at any of the locations, and only minor alterations in elongation.

In like manner, the A.S.T.M. tests (13) on die-cast specimens 0.25 in. in diameter have shown that aluminum alloys are available which do not lose appreciably in tensile strength or elongation after a five-year exposure at any of their five outdoor locations. Similarly, the tests of sand-cast and of forged alloys conducted by the Aluminum Research Laboratories, in both cases using the standard round tension-test specimen (one-half inch diameter), after five years' exposure at the various locations have shown no appreciable loss in tensile strength or elongation for several of the alloys.

Thus, it appears that aluminum alloys are available in the wrought, cast, or forged form which, in thin sections, are not appreciably affected by periods of atmospheric exposure at least as great as five years' duration.

RESISTANCE TO FRESH WATER

Studies of the rate of attack of aluminum by various waters have been made by Seligman (13), Hatfield, (14) Bengough and Hudson (15) and others. The results of these investigations, coupled with a large amount of findings from actual service installation, lead to the following generalizations.

The rate of dissolution of aluminum and most of its alloys by distilled water is negligible. In fact, aluminum is widely employed in containers and piping for handling distilled water in chemical laboratories where a minimum of solids is desired in the water.

For other types of fresh or industrial waters the suitability of aluminum depends entirely on the specific substances dissolved in the liquid as well as on other factors such as the temperature and velocity of flow of the liquid, etc. Certain factors are known to reduce the resistance of aluminum to industrial waters. For example, dissolved heavy metal salts are likely to cause attack of aluminum alloys, especially if chlorides are simultaneously present. However, laboratory investigations have shown that frequent cleaning with steel wool of pans in which water, containing heavy metal salts, was being boiled, greatly reduced the severity of corrosion. Attack by heavy metal salts appears to be only a special case of the well-known galvanic corrosion which occurs when two dissimilar metals are exposed in electrical contact with each other in a conducting liquid. Cleaning the surface of the pan removes particles of the heavy metals, precipitated there from the solution, thus reducing galvanic attack of the aluminum.

In addition, alkaline waters with a pH much above 8.5 are often corrosive. This can be attributed to actual dissolution of the oxide film which ordinarily covers and protects the surface of the aluminum. The presence of appreciable amounts of substances such as silicates, borates, and phosphates reduces the action of alkaline waters on aluminum.

In many installations in fresh water the use of aluminum has been found to be entirely satisfactory. Since some waters do have appreciable action on aluminum, wherever possible actual tests with the particular water in question should be made.

RESISTANCE TO SEA WATER

Investigations of the behavior of aluminum on exposure in sea water have been made by several workers, including Friend (16), Meissner (17), Bengough and Hudson (15), and Hatfield (14). In addition, studies of the action of sea water on various aluminum alloys have been made by the Aluminum Research Laboratories. These results indicate that the Alclad alloys and 52S and 53S are very resistant to attack by sea water.

Exposure to 20 per cent sodium-chloride spray for periods up to eight years in duration has been found to cause no significant change in the physical properties of Alclad 17S-T tensile specimens 0.064 in. in thickness. Similar exposures for the longest period investigated up to the present time (more than two years) were found to produce no alteration in the tensile strength of 52S or 53S and only minor reductions in elongation.

Alclad 17S, Alclad 24S, and 53S have been employed more and more widely in increasingly severe marine exposures with excellent results. Large transport planes, which are occasionally subjected to salt spray, are constructed of Alclad 17S or Alclad 24S without the use of protective paint coatings. Sea planes, which are subjected to more severe exposures, are now commonly constructed of painted Alclad sheet while in recent experimental applications bare Alclad materials have been employed. On boats, bare or painted, 53S has found use for such applications as deck houses, masts, airports, and bulkheads. The results of these various applications have confirmed the indications of the laboratory tests, so that it is safe to predict that these alloys and 52S will find increasing use in marine equipment.

The less-resistant aluminum alloys can also be satisfactorily used in marine locations if they are properly protected by various coatings. The Alumilite process, mentioned earlier, offers a convenient method for improving the oxide layer on such alloys. The coating thus formed is an excellent base for paints of all kinds. The most suitable painting procedures have been studied by Edwards and Wray (18). They conclude that the most effective procedure for marine use is a priming coat of zinc chromate (or iron oxide plus zinc chromate) in synthetic-resin vehicle, followed by two or three coats of aluminum paint made with the same type of vehicle.

In marine applications contact with other metals, particularly nickel and copper and their alloys, should be avoided because of their electrolytic action. When use of dissimilar metals cannot be avoided, electrical contact between them can be prevented by suitable insulating methods, which at the same time provide protection to the aluminum.

RESISTANCE TO OTHER SALT SOLUTIONS

The resistance of aluminum and its alloys to salt solutions depends largely on the particular salt under consideration. The effect of various solutions on aluminum has been studied by Hale and Foster (19), Hatfield (14), and Callendar (20). In general, for neutral or nearly neutral solutions, the sulphates,

nitrates, and phosphates have very little effect on most aluminum alloys at room temperature. The halogen salts (fluorides, chlorides, bromides, and iodides) are more active so that greater precautions must be taken in the use of aluminum in contact with their solutions.

Alkaline salts, such as sodium carbonate or tri-sodium phosphate, attack aluminum readily, especially in concentrated solutions. Seligman and Williams (21) have pointed out, however, that attack by such solutions can be greatly reduced by the addition of sodium silicate.

Acid salts like ferric, aluminum, or ammonium chlorides, are quite corrosive to aluminum; as are also solutions containing simultaneously halogen and heavy metal (copper, lead, nickel, tin, etc.) salts.

RESISTANCE TO MINERAL ACIDS

In acids, as in salts, the halogen radicals form compounds which seem to be much more corrosive to aluminum than are other mineral acids. Work described by Hale and Foster (19), Hatfield (14), Whitman and Russell (22), Poe, Warnock, and Wyss (23), and Frary (24) illustrate this. Hydrofluoric, hydrochloric, and hydrobromic acids have appreciable action on aluminum in all but the lowest concentrations. Dilute solutions of sulphuric acid or of nitric acid have only slight action on aluminum at room temperature, provided these substances are not contaminated with certain impurities such as chlorides or heavy metals. Fuming sulphuric acid and concentrated nitric acid, if uncontaminated, have very little action on aluminum. Solutions of these acids in intermediate concentrations are more corrosive. In common with many other chemical reactions, rise in temperature greatly increases the rate of dissolution of aluminum in acids. Concentrated nitric acid is handled extensively in aluminum tanks, pipe, shipping drums, and other equipment. In fact, aluminum is one of the few metals approved by the Interstate Commerce Commission for shipment containers for nitric acid over 80 per cent in strength (25).

Sulphurous acid is less corrosive than is sulphuric acid and attacks aluminum only slowly at room temperature in solutions up to 1 normal.

Phosphoric acid attacks aluminum only slowly in dilute solutions but the rate of attack becomes more pronounced at higher concentrations.

The rate of attack by boric-acid solutions is slow at all concentrations up to saturation.

RESISTANCE TO ORGANIC ACIDS

Various investigators, including Hatfield (14), Seligman and Williams (26), and Frary (27), have studied the action of certain organic-acid solutions. Possibly the most complete investigation in this line is that of Poe, Warnock, and Wyss (28). Findings of these workers, supported by the results of a large number of industrial applications, have shown that, with a few exceptions, attack of aluminum by organic-acid solutions at room temperature is very slow. Thus, aluminum equipment is widely used in handling acetic-acid solutions in a wide range of concentrations and at temperatures up to the boiling point. Very concentrated acetic acid (above 99.7 per cent pure) has been reported to attack aluminum fairly rapidly (27). The higher homologues, propionic acid, butyric acid, etc., behave similarly to acetic acid.

Although solutions of most organic acids have no appreciable deleterious action on aluminum, formic acid, oxalic acid, mono- and tri-chlor acetic acids corrode aluminum rather severely under some conditions. That this is not true under all circumstances is indicated by the fact that one large installation of aluminum equipment has been used in the manufacture of oxalic acid and no difficulties have been reported (29).

RESISTANCE TO ALKALINE SOLUTIONS

Aluminum is readily attacked by sodium- or potassium-hydroxide solutions (14, 19). Ammonia solutions, if free of heavy metals and chlorides, do not seriously attack aluminum (27), so that aluminum has been successfully employed in condensers for ammonia-water mixtures, in refrigerating systems using ammonia and in ammonia-recovery equipment.

RESISTANCE TO ORGANIC SOLVENTS

Aluminum is not appreciably attacked by a wide range of organic solvents such as benzene, carbon disulphide, acetone, and gasoline, as long as they are uncontaminated by certain other substances. It is also very resistant to halogenated hydrocarbons, such as carbon tetrachloride, provided these have not been hydrolyzed by contact with moisture. Suitably anodized aluminum has been found to be quite satisfactory for handling carbon tetrachloride even when considerable moisture is present and at elevated temperatures.

Alcohol solutions are without effect on aluminum in most concentrations. It has been found, however, that these liquids, like many other organic materials, will attack aluminum when they are sufficiently anhydrous. Such attack is most pronounced at elevated temperatures.

RESISTANCE TO GASES

Aluminum is inert toward most anhydrous gases. Its use in refrigerating units employing sulphur dioxide or ammonia has been approved by the Underwriters Laboratories (27). Aluminum is unaffected by dry or even moist hydrogen sulphide (30) and by dry carbon dioxide, nitrous gases, oxygen, hydrogen, or chlorine. It is only very slightly affected by the joint action of moisture and carbon dioxide, oxygen, or hydrogen. Moist nitrous gases have a slight action on aluminum and moist chlorine readily attacks it.

INDUSTRIAL APPLICATIONS

Earlier in the paper various industrial applications of aluminum have been mentioned. These references were employed to illustrate specific points and do not embrace the wide variety of uses which have been made of aluminum. The extensiveness of these applications and their widely different requirements make it desirable to discuss each group of uses independently.

PREPARATION AND DISTRIBUTION OF FOODS

Possibly the most generally appreciated use of aluminum is in the form of pans and kettles in the home kitchen. Here its combination of properties, lightness, high heat conductivity, resistance to attack by foods, and the harmlessness of the compounds formed by the substances which may react with it, make aluminum the ideal metal for the job. As might be expected, aluminum and its alloys are also widely used in the large-scale commercial preparation of foods. Breakfast-cereal cookers, milk-processing and storage equipment, and cheese vats are made of aluminum alloys. In the preparation of gelatin, aluminum is employed in cooking and storage tanks, in filtration equipment, evaporators, drying trays, and screens. It is extensively employed in the preserving and bottling industries in contact with such fruit products as cranberry sauce, grape juice, pineapple preserves, and orange marmalade. In the edible-oil and fat industry aluminum is used in storage, bleaching, deodorizing, and winterizing tanks. In the manufacture of beer, aluminum equipment finds application in practically all stages in the process. Yeast and wort coolers, brew

kettles, filters, fermenters, aging tanks, valves, and piping are all made of aluminum, while aluminum barrels for shipping beer are extensively employed. Aluminum caps and seals are used in bottling liquors, food products, and medicines, while foil wrappers find wide application in packaging candy, cheese, and tobacco. In these uses the alloys of aluminum more generally employed are 2S, 3S, or pure aluminum.

TRANSPORTATION

Many of the most impressive uses of aluminum alloys have been in the transportation fields. Aircraft are largely constructed of the strong aluminum alloys such as 17S, 24S, Alclad 17S, or Alclad 24S. Buses, trucks, passenger coaches, tank cars, and hopper cars also utilize aluminum alloys. In such applications structural members are often made of 17S-T, while panels for bodies, tanks, and the like, for which the highest strength is not required, are constructed of 3S-$^1/_2$ H. Forged crankcases for radial aircraft engines, which must be strong and rigid and capable of withstanding extreme vibratory stresses for long periods of time at temperatures up to 250 F, are made of A 51S alloy. Pistons are made of forged 32S or cast 122 or 132 alloys while aircraft cylinder heads are cast from 122 or 142 alloy. The more resistant alloys, such as 52S and 53S, have found application in fast ships, both power boats and sailing yachts. Such vessels have been, in some cases, constructed practically entirely of aluminum alloys; in others, only special members have been made of these materials. Aluminum masts, superstructure, and interior trim have been especially widely employed. Deck plates, hatch covers, airports, grilles, and window sashes are applications on the exterior of large passenger vessels now constructed of aluminum alloys, while aluminum furniture, bulkheads, and insulation are widely employed aboard such vessels. Recently light aluminum bicycles have been much in demand. Lightness, strength, resistance to corrosion, and noninflammability are qualities which make the aluminum alloys so well adapted for utilization in the transportation field.

Allied with this is the employment of the alloys of aluminum in elevators, skips, hoists, and cranes. Such equipment finds wide use in gold, silver, copper, and coal mines. One particularly interesting application is in a salt mine where an aluminum elevator, made of 53S alloy, is employed to raise mine workers and rock salt the 2000 ft from the bottom of the shaft to the surface. In this location, the elevator has been subjected to continuous contact with moist sodium chloride from the time it was installed, two years ago, up to the present date. Even after this severe exposure no serious attack of the metal has occurred.

THE ELECTRICAL INDUSTRY

In the electrical industry, steel-reinforced aluminum cables have found wide use in transmission lines, while aluminum bus bars for indoor or outdoor service are much employed. Outdoor meter boxes, switch boxes, and control cabinets of die-cast aluminum alloys are enjoying a large and growing application, while caps to lightning arresters and coupling capacitors of sand-cast aluminum alloys, such as 12, 43, and 195-T4, are now being constructed. In outdoor lighting, aluminum reflectors prepared by the "Alzak" (31) process are finding an increasing use. Here the somewhat lower initial reflectivity of the treated aluminum surface, as compared to a silvered reflector, is more than offset by its nontarnishing characteristics. This means that such reflectors maintain their high reflectivity for longer periods of time than silvered reflectors when exposed to the outdoor atmospheres. Thus the electrical industry makes use of qualities of aluminum such as its high electrical conductivity, and good light reflectivity, as well as its resistance to corrosion, strength, and lightness.

CHEMICAL INDUSTRIES

To the highly varied requirements of the chemical industries aluminum has shown a great adaptability. At the basis of these industries, in the control or research laboratories, aluminum storage tanks, valves, and piping are employed in the distribution of pure distilled water. Here freedom from contamination in the delivered liquid is of utmost importance and aluminum equipment well fulfills this requirement. In the manufacture of rayon, forged, enameled 53S spinning buckets and uncoated bobbins of pure aluminum find general usage to withstand these severe exposures to sulphuric-acid solutions. Tanks and piping used in desulphurizing rayon, ducts, and ventilating systems to handle air contaminated with large amounts of hydrogen sulphide, and tubular heating elements in the air-conditioning equipment are all constructed of aluminum. Water needed for washing the thread is commonly conveyed in pure-aluminum pipe since staining of the thread is impossible by any products formed from the aluminum. In the preparation of cellulose acetate, aluminum rotary driers find application, while package-drying machines of aluminum are employed in the preparation of threads and yarns. In the manufacture of naval stores, distillation towers, condensers, and tanks of aluminum alloys are utilized for the separation and purification of turpentine, pinene, and allied products. Fatty acids are handled in aluminum condensers, cooling trays, and storage tanks, while pure-aluminum pans are employed in the manufacture of citric acid. Tartaric acid is stored, filtered, and crystallized in aluminum equipment and aluminum is extensively used in the preparation and storage of acetic acid. The use of aluminum in the preparation of ammonium nitrate is especially interesting since the product produced in aluminum equipment is not spontaneously explosive as is the case when equipment of certain other metals is used. In addition, the nonsparking characteristics of aluminum are important in such installations. Artificial resins are often prepared and stored in aluminum reaction vessels, condensers, and tanks, and aluminum storage tanks are used for formaldehyde. Aluminum shovels, utilized in the bulk handling of chemicals, possess many advantages; the most important of which are possibly their nonsparking qualities, lightness, and freedom from the possibility of producing stains or discoloration in the substances handled.

The lightness of aluminum makes it highly desirable for use in shipping containers. In America the following chemicals are now shipped in aluminum containers: Acetaldehyde, benzaldehyde, methyl salicylate, paraldehyde, essential oils, acetic acid, acetic anhydride, formaldehyde, butyric anhydride, nitric acid, lacquers, and hydrogen peroxide. It is probable that this list will be rapidly enlarged, since many other chemicals are known to be unaffected by contact with aluminum.

REFRIGERATION AND AIR CONDITIONING

In refrigeration and air-conditioning equipment, food shelves, cooling coils and fins, ice-cube trays, evaporator and service-drawer fronts are made of aluminum. Here the resistance to staining and corrosion and high heat conductivity are important. In insulating refrigerators, aluminum foil is successfully used. In this case the good heat reflectivity is the most important quality. For many applications, the lightness which results from the low specific gravity and the extreme thinness of the foil is a distinct advantage.

ARCHITECTURE

One of the earliest uses of aluminum for architectural pur-

poses was as a cap for the Washington Monument. This was installed more than 50 years ago (December 6, 1884), and was found to be in excellent condition at the time of a recent inspection (32). Similarly, an aluminum statue of Eros, erected in London in 1893, has been little affected by its long period of exposure. Since this material has such excellent stability under atmospheric conditions it is not surprising that there is an increasing use of aluminum in architectural installations.

In the newer buildings decorative spandrels are often made of 43 alloy castings. (The castings may be used without special surface treatment although they are usually given an anodic oxide finish which may be relieved by mechanical treatment to produce high lights on the raised portions of the casting.) Where greater strength is required, castings of 195 or 356 alloys are commonly employed. Window sections, sills, store fronts, and miscellaneous exterior trim are made of extruded 53S. In grilles, building hardware, and ornamental parts, permanent-mold castings of 43 or 195 alloys are much used. In structural members the strong alloys, such as 17S-T, find application. Doors, gates, and entrances are often constructed of cast or wrought aluminum alloys, either uncoated or given various decorative coloring treatments. Statuary for outdoor or indoor use is frequently of cast aluminum alloys whose lightness and strength give increased scope to the artist's technique. Sheet aluminum and aluminum shingles are used for roofing; flashing, gutters, and downspouts are also made of aluminum.

Since aluminum members have been employed for such a variety of architectural uses, it is not surprising that at least one large building has been constructed almost entirely of aluminum. An all-metal office building (33), designed and erected by the Department of Public Works, Richmond, Va., makes use of aluminum in the doors, entrance, pilasters, entablature, spandrels, facades, interior and exterior walls, partitions and trim. Incidentally, it is interesting to note that this structure was the most desirable, not only from a financial standpoint but also from the standpoint of usefulness, of the seventeen propositions which had been submitted previous to its construction.

MISCELLANEOUS USES

In the severely corrosive environments encountered in sewage-disposal plants, aluminum equipment and architectural and structural members find useful application.

Rubber toys, bathing caps, etc., are produced on aluminum molds. Here resistance to the action of sulphur is requisite.

A large and growing application of aluminum is in the manufacture of hookless fasteners. The lightness and resistance to tarnish and corrosion make aluminum almost the ideal material for such uses.

This by no means exhaustive list of applications of aluminum may help to indicate the widely varying uses to which this versatile metal has been put. In these applications advantage has already been taken of many of the characteristics of aluminum and its light alloys, but it seems safe to predict that as greater knowledge of the qualities of these materials becomes available, additional and possibly different applications will result.

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Corrosion-Resistant

LEAD EQUIPMENT

By GEORGE O. HIERS

NATIONAL LEAD COMPANY, BROOKLYN, N. Y.

LEAD is widely used in equipment in the chemical industry on account of its corrosion resistance and for reasons of economy. Some of the mechanical and physical properties of lead are advantageous, as for instance, its plasticity, softness, and low melting point, which allow easy working, such as bending and welding. From a mechanical viewpoint it is notably weak and therefore careful design is necessary in construction work. Hard, or antimonial, lead is used where its slightly greater strength is sufficient; if more strength is required lead-lined or covered steel or copper is used.

COMPOSITION

For construction purposes in chemical plants lead has usually been either the grade known as chemical lead or hard lead, while occasionally a pure commercial grade is required. The undesilverized lead from southeastern Missouri which contains small amounts of copper, silver, and nickel has long been a favorite in the chemical process industries, and is specified by the A.S.T.M. (1).[1] Hard lead with from 6 to 12 per cent antimony also finds considerable use where the temperature does not exceed 100 to 120 C. Some use is occasionally made of lead containing lesser amounts of antimony, while a recent report from England describes the use of a lead with as much as 28 per cent antimony (2). Examples of the composition of some standard grades are given in Table 1.

A recent British discovery of importance is a soft lead containing about 0.05 per cent tellurium (3). This is a chemical type of lead and its superior properties will be dealt with later. Alloys of similar amounts of tellurium added to antimonial lead are used in the chemical industry (19). Leads containing 7 per cent tin find special use as anodes, heating coils, and tank linings, with chromium-plating solutions (5). An alloy of lead with 1 per cent silver is used for insoluble anodes in the electrolytic refining of zinc (18) and for coating air-conditioning radiators.

PHYSICAL AND MECHANICAL PROPERTIES

A few of the more important constants of lead are given in Table 2. Some of these properties are necessarily affected by the impurities present. The minimum recrystallization temperature of pure lead (or the so-called "equicohesive temperature") is approximately minus 30 C. No allotropic forms of lead have been found by Rawdon (6). The effect of other elements on the recrystallization of lead is an important matter, concerning which there is little in the literature.

The mechanical properties of lead have recently been studied somewhat more intensely. Since lead at ordinary temperatures may be considered as tending more toward a plastic solid than a rigid one, wide values can be given to almost any mechanical property. Slight changes in composition can cause wide limits of values.

TABLE 1 COMPOSITION OF STANDARD GRADES OF LEAD

	"Chemical"	Purest commercial	Common	Corroding (for making white lead)
Silver	0.0068	0.00055	0.0005	0.0005
Copper	0.062	0.0003	0.0003	0.0003
Arsenic	None	Trace	Trace	Trace
Tin	None	None	Trace	Trace
Antimony	0.001	0.0012	0.001	0.001
Bismuth	Trace	Trace	0.089	0.045
Cadmium	0.0008	0.0006	0.0003	Trace
Zinc	0.0002	0.00024	0.0001	0.0002
Iron	0.0002	0.0003	0.0004	0.0002
Nickel and cobalt	0.0048	Trace	0.0004	0.0002
Manganese	Trace	Trace	Trace	Trace
Lead (by diff.)	99.924	99.9968	99.9090	99.9528

TABLE 2 PHYSICAL PROPERTIES OF LEAD

Atomic weight	207.22
Atomic volume	18.27
Density, 20 C, cast	11.34
327.4 C, solid	11.005
327.4 C, liquid	10.686
550 C, liquid	10.418
Melting point, C	327.4
Boiling point, C	1525–1620
Spec. heat, per C	0.0302
Latent heat of fusion, g-cal per g	5.47–6.26
Latent heat of vaporization g-cal per g	223
Thermal conductivity, 0 C, g-cal	0.083
Coef. of linear expansion (17–100 C), per C	0.0000293
Brinell hardness	3.2 to 6.0
Elastic limit, lb per sq in	284
Modulus of elasticity in tension	0.8–2.0 million

The endurance limit under several million cycles of alternating stresses or vibration plays an important part in the failure of lead. Of the results of attempts to devise mechanical tests which simulate failures in service, those made on the Haigh machine are given in Table 3 as they have been reported by workers in England. Excellent work on the endurance limits of lead cable-sheath alloys has been reported by the Bell Laboratories (10) and by the University of Illinois (9).

Since the values at hand for the recently developed calcium lead are results from different types of testing machines, they are not cited here, but it may be noted that undoubtedly they fit in the higher-value brackets.

The tensile strength of lead as well as its hardness varies according to its condition and composition. The general approximation of data from many sources, Table 4, gives a better picture of this property than a grouping of results from isolated tests made under varying conditions. It is unfortunate that there appears to be no reference in the literature of tensile tests of a great number of different leads under exactly similar conditions, and with a clear knowledge of the rate of straining.

The addition of certain other elements raises the recrystalli-

[1] Numbers in parentheses refer to Bibliography at end of paper.

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TABLE 3 ENDURANCE TESTS ON HAIGH MACHINE CONVERTED TO LB PER SQ IN.

Material	Observer A	Observer B	Observer C	Good approximation
Pure commercial (99.9 lead).....	403	..	403	400
Chemical (0.06 Cu).............	..	..	627	600
Tellurium[a] (0.06 Te)............	..	762	1120	1000
3 per cent tin....................	1220	1120	..	1100
1 per cent antimony.............	1455	..	..	1300
Ternary (0.25 Cd + 1.5 Sn).....	1278	..	1278	1100
Ternary (0.25 Cd + 0.5 Sb).....	1658	..	1658	1500

A = Beckinsale and Waterhouse (7).
B = Waterhouse (8).
C = Russell (9)
[a] As brought out in discussion by Waterhouse, since this lead has marked work-hardenability, the condition of strain is important. The maximum of 0.50 tons per sq in. (1120 lb per sq in.) has generally been quoted in numerous places, but the commercial forms would usually appear to show a somewhat lower endurance limit, say 900 lb per sq in.

TABLE 4

	Ultimate tensile strength rate 0.25 in. per in. per min	Elongation, per cent	Average Brinell hardness number
99.9 per cent pure..............	1750–1900	55	3.5–4
Chemical (0.06 Cu).............	2190	50	4.5
	2600[a]	56	..
	2765[c]	50	..
Tellurium (0.06 Te)............	3420	32	5.8
	2770[a]	37	..
Ternary (0.25 Cd — 1.5 Sn).....	3780[d]	62	5.7
Ternary (0.25 Cd — 0.5 Sb).....	3760[d]	58	6.5
Hard lead (6 per cent Sb).......	6700[c]	22	11.8
Hard lead (6 per cent Sb).......	4500[r]	50	7.5
Hard lead (8 per cent Sb).......	7450[c]	22	13.4
Hard lead (8 per cent Sb).......	4780[r]	50	8

[a] Annealed. [c] Cast. [r] Rolled. [d] Rate = 0.6 in. per in. per min.

zation temperature and retards stress relief and grain growth. Tellurium, copper, and calcium have marked effects in this direction. The grain size of the metal remains in a fine condition for long periods. Tellurium lead work-hardens, while calcium lead is susceptible to dispersion hardening with aging.

The elongation of lead varies somewhat with the rate of application of the load. Attention has more recently been drawn to the gradual elongation of lead under small constant loads over long periods of time. Creep tests are in progress both here and in England, but conclusions are only tentative (12). It can only be said that the safe working pressure or creep limit of lead is approximately a fiber stress of 200 lb per sq in., at room temperatures with some variation, plus and minus, depending on composition or metallurgical history of the material.

In the design of steam-heating coils made of lead pipe and other lead chemical equipment, the suggested maximum allowable fiber stresses may be used, as in Table 5.

The fatigue strength and creep strength are important physical properties affecting the life of lead. Corrosion resistance is a complex property, but in service conditions it is almost inevitably related to mechanical properties to a lesser or greater degree.

AVAILABLE COMMERCIAL FORMS

Soft, chemical, and tellurium sheet lead are made by cold-rolling, while hard-lead sheet is made by hot-rolling. Crawl-proof lead is made by rolling and is chemical lead reinforced with internal rods or ribs of hard lead. These sheets are available commercially in sizes up to about 12 by 40 ft. Thicknesses are obtainable ranging from $^1/_{64}$ to 1 in. or more on special order. The gage of the sheet is referred to by its weight in pounds per square foot. Lead one inch thick weighs 60 lb per sq ft and thus, obviously, for the lighter stock one can, without serious error, take the number of sixty-fourths of an inch of thickness as the weight in pounds per square foot. Ribbons, strips, and gaskets, may be obtained from rolled sheet.

TABLE 5 FOR CALCULATING SAFE WORKING PRESSURE OF LEAD PIPE AT VARIOUS TEMPERATURES

(Data from Lead Industries Association (13))

Temperature C	Temperature F	Equivalent steam pressure, lb per sq in., gage	Maximum allowable fiber stress, lb per sq in. Chemical lead	Maximum allowable fiber stress, lb per sq in. 6 per cent antimonial lead
20	68	...	200	400
30	86	...	190	370
40	104	...	180	340
50	122	...	172	310
60	140	...	162	280
70	158	...	153	254
80	176	...	144	222
90	194	...	136	195
100	212	0	127	165
110	230	6	118	137
120	248	14	110	110
130	266	24	100	80
140	284	37	90	50
150	302	54	80	...
247	477	535	...	0
327	621	...	0	...

The formula to be used with the values in the table is $P = 2ST/D$
Where P = safe working pressure, lb per sq in.
S = maximum allowable fiber stress from table.
T = thickness of pipe wall, in.
D = internal diameter, in.
Sometimes it is advisable to use wall thicknesses greater than those derived from the equation for mechanical or structural reasons. Where corrosion is anticipated, it is well to provide additional wall thickness.

Strip, rod, or ribbon is often manufactured by extrusion but by far the largest amount of extruded product is lead tube or pipe. Sizes from $^1/_{16}$ to 12 in. internal diameter are readily available in 20-ft straight lengths or in coils of considerable length of up to 200 ft, according to the caliber.

Many different forms of extruded products are available. Spacer blocks for heating coils are occasionally extruded and cut in appropriate lengths. Oval pipes, regular traps and bends, rods, and wires are obtainable.

CORROSION

While lead is principally used for equipment for handling sulphuric acid, either alone or in the wide industrial use in combination with other acids or salts of the acid, it also finds considerable use with other agents and in contact with the soil or atmosphere. Its durability is related to a protective film or coating of corrosion product. This may be anything from an oxide tarnish to a heavy coat, but it is obvious that insolubility is a prime factor. The physical properties of this protective film are highly important and the rate of corrosion may vary considerably under apparently similar conditions. The self-healing or "maintaining" characteristics of protective films on lead are noteworthy. Lead is an important corrosion-resistant metal because of them. In general, lead resists the atmosphere, natural waters, and most mineral acids in which an insoluble product is formed.

The conflicting results of many laboratory tests of the statistical type have been well gathered and concisely stated by McKay and Worthington (14). Such results force the users of lead to conclude that the knowledge of corrosion resistance

TABLE 6 CORROSION RATES OF LEAD

LEAD VS. AQUEOUS AMMONIA
(1-N solution 48-hr periods)

	Mg per sq dm per day
Total immersion	
Quiet	15
Air-agitated	9
Alternate immersion	
Continuous	29
Intermittent	25
Spray (30 days)	3

LEAD VS. SALT SOLUTIONS

(Quiet, 46 F, 200 days)

Salt	Conc, grams per liter	Mg per sq dm per day
Water (no salt)	...	0.46–60
Sodium chloride	2.5–60	1.8–9.7
Potassium chloride	2.5–15	3.4–7.0
	40–80	0.69–0.80
Potassium nitrate	5–100	7.4–24
Sodium sulphate	2.5–20	0.24–0.72
	50–200	0.021–0.039
Potassium sulphate	2.5–80	0.11–0.80

LEAD VS. SALT SOLUTIONS

(14 months)

	Mg per sq dm per day
Calcium carbonate	2
Calcium bicarbonate	1.3
Sodium carbonate	5.2
Magnesium sulphate	2.2

LEAD VS. CAUSTIC SOLUTION

(1-N solution of NaOH room temp, 2-day periods)

	Mg per sq dm per day
Total immersion	
Quiet	74
Air-agitated	370
Alternate immersion	
Continuous	5500
Intermittent	2200
Spray (30 days)	9.5

LEAD VS. PHOSPHORIC ACID

(Quiet, 250 hr, 60 F)

Concentration	Mg per sq dm per day
Pure acid	
76 per cent	450
42 per cent	160
Impure acid	
42 per cent	1

(Aerated, 176 F)

Concentration	Mg per sq dm per day
Pure acid	
50 per cent	580–1150
25 per cent	400–1420
10 per cent	35–720
Crude acid	
Dilute	1 to 7
Concentrated	2.1 to 2.3

LEAD VS. SULPHURIC MIXTURES

(77 F)

Acid concentration per cent: Sulphuric	Hydrochloric	Nitric	Mg per sq dm per day
			10
20	..	..	10
18	2	..	320
15	5	..	1,790
10	10	..	4,890
5	15	..	8,560
2	18	..	13,000
18	..	2	24,000
15	..	5	very great
10	..	10	very great
5	..	15	very great
2	..	18	very great

LEAD VS. ACIDS

(Quiet, room temp (15))

Acid	Mg per sq dm per day: 4 hr	28 days
Nitric, 1.2 per cent	2200	230
Hydrochloric, 7 per cent	360	25
Sulphuric, 1 per cent	60	1

(Gas bubbling through solutions 68 F 5-hr period (16))

Acid	Mg per sq dm per day: Oxygen	Hydrogen
Sulphuric		
6 per cent	79	79
20 per cent	118	47
50 per cent	134	95
93 per cent	335	292
Hydrochloric		
4 per cent	1,280	134
20 per cent	8,700	870
Nitric		
30 per cent	68,500	64,600
70 per cent	1,360	768
Acetic		
6 per cent	8,200	2130
Glacial	50,000	4560

(Agitation-aeration, I-N acids, room temp, 48-hr periods (17))

	Mg per sq dm per day: Hydrochloric	Acetic
Total immersion		
Quiet	111	111
Air-agitated	330	730
Alternate immersion		
Continuous	840	13,500
Intermittent	360	4,430
Spray (30 days)	119	2,050

HARD LEAD VS. HYDROCHLORIC ACID

Acid concentration	Mg per sq dm per day: Temp, 68 F	Temp, 212 F
1 per cent	10	10
5 per cent	10	60
10 per cent	20	60
35 per cent	100	240

is best based on experience from actual service or service tests and the exact chemical nature of the reacting substances. Furthermore, attempts to extrapolate rates of corrosion based on short-time tests may be misleading. Such terms as milligrams per square decimeter per day, or inches penetration per month are offered merely as a guide to the user.

Hedges has shown that the rates of corrosion of some types, specifically those with protective coatings, are logarithmic in type (27). The rate of corrosion eventually approaches zero as a limit. The water pipe dug up in Rome after being in the ground 2000 years, in perfect condition, is a good example of this type of corrosion. The troublesome types of corrosion are

more particularly those evidenced by pitting or cracking where a metal may fail quickly due to some localized action, such as galvanic action, stress corrosion, or differential aeration.

With these limitations some of the rates of corrosion which have been found in the literature and which have been compiled by McKay and Worthington (14) are presented in Table 6.

Considerable lead is used for roofing purposes, in which case hard lead is generally employed. Storage-battery grids, came lead, traps, bends, and waste pipes, as well as service pipes, are other applications generally considered too specialized and detailed to discuss here. It may be mentioned in passing that the use of lead pipes or containers for very soft drinking waters and those containing magnesium chloride, or a high content of free carbon dioxide, is to be avoided—not so much on account of the slightly lessened life of the pipe, but because of danger to health. For conveying soft drinking water, tin-lined lead pipe may be used.

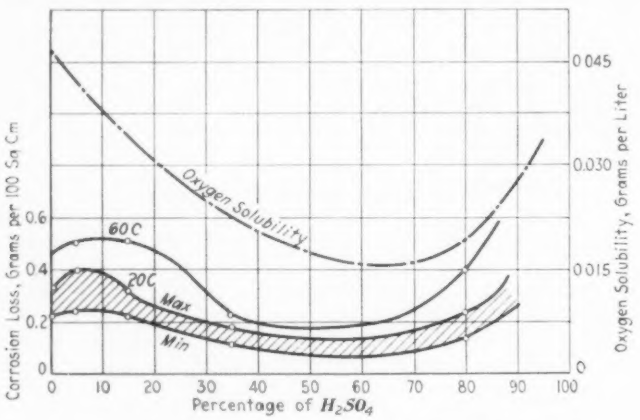

FIG. 1 CORROSION LOSS OF LEAD IN EXPOSURE TO H_2SO_4

(8 weeks, 20 C air-saturated acid; 4 weeks, 60 C air-saturated acid.)

Fig. 1 shows the corrosion loss of lead exposed to sulphuric acid of various strengths. The curves are the result of a few immersion tests made in the usual manner. In determining losses, the coatings were carefully removed with the aid of ammonium acetate and added to the apparent loss in weight giving a true total loss. There is a peak at between 5 and 10 per cent acid, which is around the strength used for the pickling of steel. Nevertheless, numerous lead-lined pickling tanks are successfully employed in steel mills.

Sometimes a high-temperature lead is required for use with strong acids. In the sulphuric-acid industry, large tonnages of lead at elevated temperatures are required. For such purposes hard lead is not suitable and the need of a chemical type of lead for use is indicated. Tellurium lead is a very good high-temperature lead and may extend the life of equipment. This is perhaps evident from flash-test results with sulphuric acid as indicated in Table 7.

TABLE 7 FLASH TESTS

(90 per cent acid, 3 min at temperatures noted)

	Loss, per cent	
	At 313 C	At 304C
Chemical (0.06 Cu)	6.35	5.1–5.6
Tellurium chem. (0.06 Te)	2.29	1.2
Pure commercial (99.99 Pb)	23.1	19.1–19.8
8 Per cent antimonial	(100%)[a]	(100%)[a]
Very pure twice-refined electrolytic (99.9994 Pb)	...	4.5–5.0

[a] Failed before noted temperature attained. Tests made by method described (29).

The value of the flash test has rightly been depreciated and is clearly limited to indications of suitability for use at high temperatures. It may be, also, of some value to the small user as a substitute for more expensive complete chemical analysis. Copper, nickel, and tellurium leads give good results in the flash test, while objectionable impurities cause the lead to disintegrate at temperatures well below 300 C. Otherwise this test has but little meaning. It should be noted that antimonial or hard lead resists sulphuric acid quite well in the cold.

Numerous attempts to strengthen lead mechanically have been made. This can be accomplished by introducing amounts of other elements, related to requirements as to their solubility in lead. From the corrosion standpoint, it may be noted that most of these attempts tend to sacrifice the natural corrosion resistance possessed by the pure metal. Against such acids as phosphoric, acetic, hydrochloric, or nitric, no substantial improvements have resulted by alloying. With sulphuric acid, copper, nickel, and tellurium appear to show a benefit by assisting the formation of a better protective coating, particularly at elevated temperatures. With chromic acid, or salts thereof, a 7 per cent tin alloy has proved to be useful in prolonging the life of electroplating equipment. It does not appear to require frequent periodic anodic treatment in order to prevent drastic corrosion which occasionally occurs when some other varieties of lead are used without anodic treatment (5). With water or under wet atmospheric conditions, or in some soils, a lead with up to 3 per cent tin has shown best resistance. In electrolytic zinc refining a noticeable improvement in the life of lead anodes was made by the addition of around 1 per cent silver (18). This alloy may be said to have indirectly given an impetus to the zinc die-casting industry by introducing commercial zinc of high purity (99.97 per cent) which has resulted in dependable alloys.

EQUIPMENT DESIGN AND USE

In a previous section commercial forms of pipe and sheet were discussed as available products. As indicated in Table 5, soft- or chemical-lead and hard-lead pipes have some limitations in strength. Chemical-lead and tellurium-lead pipes for heating coils may be safely used with a maximum steam pressure of 50 lb per sq in. In instances where higher steam pressures up to 150 lb per sq in. are desired, copper tubing covered with an adherent layer of lead of substantial thickness may be used and can readily be procured.

LEAD TANKS AND TANK LININGS

Lead tanks or stills are sometimes made without complete surrounding reinforcement. A good example is a cast antimonial-lead evaporator for concentrating titanium-sulphate solution (4). It measures 4 ft 6 in. in diameter and 7 ft in height. With the exception of the base, which is cast iron, this entire evaporator is made of a cast alloy of 92 per cent lead 8 per cent antimony. About 35,000 lb of metal were required to make the castings. The steam pressure encountered is 10 lb gage and the vacuum 26 in. of mercury. The walls of the evaporator shell are $1^1/_4$ in. thick.

Stills for making ether are usually built from lead without reinforcement of stronger metals except at flanges where iron legs may be attached.

Numerous lead tanks are made with a skeleton framework of angle iron for outside support. A large tonnage of sheet lead is used for lining tanks built of plate steel. The lead sheet is usually bolted or strapped to the steel tank which it lines, particularly with large sizes. Vertical straps are generally

preferred. They should be numerous to avoid the possibility of buckling of the lead lining due to expansion or contraction with changes in temperature or to avoid failure due to vibration. In a tank 20 ft in diameter and of similar height it may be desirable to use vertical straps 4 ft apart. The straps are of steel and rounded to prevent cutting the lead. Bolts (with special heads) are placed through the strap, sheet-lead lining, and tank shell, and fastened. An additional narrow strip of lead sheet is used to cover the bolt heads and is welded to the sheet-lead lining. Occasionally the strap is included in an overlap seam, thus halving the length of welding. The merit of the latter practice is questionable, if the service is severe. Welding or burning of lead is readily accomplished. If handling permits, tanks may advantageously be laid on their sides to facilitate the welding of the strap covering.

Oxygen with city gas, hydrogen, or acetylene may be used in torches for welding. Many lead burners seem to prefer the use of oxyhydrogen flames. Burning bars of the same composition as the sheets or pipes welded are desirable. Lap welds are most frequently made, although butt welds and welds of standing seams may be used. Many welders choose to peen the welds before they have cooled. The hammering breaks down the dendritic structure of the weld metal, making the grain size approach that of the rolled or of the extruded product joined.

Lead linings in wooden tanks of moderate size, say up to 6 ft high, are frequently supported by the sheet metal flanged over the top edges of the tank. Owing to the ease in handling lead pipe and the desirability of different types of heat-exchange coils they are made as a helix, a flat spiral (pancake) or in grid form with return bends. Often a double coil is made by placing one helix within another.

Many lead linings of tanks are further reinforced by an acid-brick lining inside of the lead lining in order to prolong the life of the lead.

PUMPS AND VALVES

Antimonial-lead sheet and pipe are frequently used in preference to chemical lead owing to their greater strength and adequate corrosion resistance to sulphuric acid at ordinary and slightly elevated temperatures. Very often in the construction of pumps and valves, 6 per cent antimonial lead is used because of its resistance to abrasion as well as its strength and anticorrosion quality. Such centrifugal pumps are of two types, the open pattern and the vertical-shaft pump. The open type of centrifugal pump is most commonly used and is similar to a standard cast-iron pump in construction, with exceptions that the casing is cast antimonial lead and all parts contacting the chemical solution are of hard lead. The advantage of the vertical pump is in the fact that no stuffing box is required, but such type has restricted use. The general purpose to which it is applied is where solutions are not to be pumped to any great distance or without much pressure or head. However they will deliver large volumes of liquid.

LEAD COATINGS OF VARIOUS TYPES

Steel pipe adherently lined with lead is considerably used. Special lead-faced flanges for joints are obtainable for use therewith. Acid valves of various types are manufactured in both lead-lined and hard-lead patterns. The type of valve usually specified is the Y pattern, or what is known as a free-flow valve. This type tends to prevent injury to the seat caused by grit. Such injury would cause the valve to leak. For some conditions, where strong acids are not being handled, or the temperature does not exceed 180 F, valves are equipped with a removable rubber plug. The advantages of the removable rubber plug are in the convenience of easily reequipping the valve with a new plug and also, to some extent, the self-seating qualities. Where conditions require, other patterns of valves can be furnished, such, for example, as the globe, gate, and angle, and, also, for pumping conditions, check and foot valves.

Lead-lined steel tanks and lead-covered copper pipes with adherent coverings of substantial thickness of lead are being successfully used in many installations. The lead is fused to the steel or copper and such equipment is called homogeneously lined or covered. Its use is becoming wider because in addition to its mechanical strength, it has the advantage of offering good heat transfer in contrast to a loose lining, which gives inefficient conduction. This type of anchorage of the lead, approaching 100 per cent as it does, tends to eliminate troubles due to thermal changes or vibration. Homogeneous equipment is usually built as storage tanks, autoclaves, jacketed pressure tanks, agitators, and propellers.

In order to prevent erosion of lead used for thickener and classifier rakes, for the lips of scoop feeders attached to ball and tube mills, and for the buckets and flights of conveyors there is a special product called "plumbalun." It is made by applying a layer of abrasive grains of aloxite over the entire surface of a hard-lead casting (20).

Sprayed-lead coatings for corrosion resistance have merit. They may be applied to the surface of assembled steel or iron equipment after the iron has been cleaned with a blast of sand or steel grit. "The relative resistance of various sprayed molten-metal coatings, applied on steel, against the attack of the corrosive agents occurring in flue gases was determined in an apparatus in which this attack is considerably accelerated and in which uniform corrosion results are obtainable. Sprayed molten-lead coatings were found to be practically unattacked. Twenty-two other metals and metal combinations, applied in sprayed molten form, indicated lack of suitability for service under conditions similar to those developed in this apparatus" (21). Spraying with tellurium-lead (metallizing) has been recommended to protect boilers, heaters, and water-storage vessels in the City of Toronto (22). The corrosion resistance of sprayed coatings is improved by burnishing, peening, or rubbing. Occasionally the porosity is rendered less objectionable by a preliminary corrosion treatment which tends to fill the pores with insoluble lead sulphate.

Lead flooring has been used to protect concrete floors, to ease the cleaning up of spills, for nonslipping, and to prevent the wear of rubber hose dragged over the floor (23). The use of lead is sometimes desirable in plants handling inflammables or explosives in order to prevent sparking. Lead table tops for industrial laboratories have been found advantageous and are said to tend to eliminate the breakage of glassware (24). Several years ago two rayon concerns in the same vicinity used more than 1000 tons of lead in the construction of their plants (25).

Lead antivibration pads or mattresses are frequently used. The outer sealed covering of lead serves to prevent disintegration of cork or asbestos which is held within. Such mattresses are used under machinery and under columns in skyscrapers (26).

The manufacture of sulphuric acid by the chamber process entails the use of great quantities of lead. The chambers for many years have been rectangular rooms made of 6-lb sheet lead for the walls and ceiling with heavier lead for the pans (10 lb) or bottoms (8 lb). The chambers may be 60 ft wide by not over 40 ft high, and the length may be as great as 236 ft. Horizontal iron rods at intervals are used to support the side walls, which are fastened by means of lead straps. The ceilings are

also strapped for support. Cylindrical chambers made of lead are now also used to some extent and they are water cooled with external sprays.

ADDITIONAL TYPICAL APPLICATIONS IN INDUSTRY

Various other chemical industries use lead in certain installations. Among these may be mentioned color works, dye works, silk manufacturers, the coke industry, and the manufacturers of perfume, glue, adhesives, soap, ink, graphite, gunpowder, as well as almost innumerable chemicals and reagents.

In the manufacture of alum, lead-lined equipment and antimonial lead are used. In the oil-refining industry lead-lined agitator tanks, dilute-acid washings, and acid-recovery systems use lead-lined equipment. In the fertilizer industry, where 52-Bé (66 per cent) sulphuric acid is commonly used with phosphate rock, lead almost always finds use in the pipe lines feeding in the acid, and sometimes homogeneous lead-lined drums are used for holding the charge while treating phosphate rock with sulphuric acid. Acid phosphate and phosphoric acid of 60 per cent strength may be shipped in lead, but it has been said that 85 per cent acid is too corrosive for lead.

In sulphite-process pulp plants, where the calcium bisulphite carries sulphurous acid, iron or tile brick are usual except in the condensing and cooling towers, where lead-lined or hard-lead equipment is used, as it is also sometimes in the suction fans. Pipe lines and pumps may be lead lined. Hot acid gases from the digester are sometimes cooled in hard-lead coils. In sugar refineries lead-lined pipe is used for circulating phosphoric acid, but erosion may be a considerable factor.

In the caustic process, lead linings are sometimes used where the concentration is not over 30 per cent at room temperature, and not over 10 per cent at 90 C. For use with acetic acid, lead is not satisfactory, except that glacial strength is sometimes used in the absence of oxygen or aeration.

Although tellurium lead has been recently taking its place as a new material in equipment, testimonials of notable service are already being received. Large tonnages are in use. A Midwest company is successfully using tellurium-lead coils as a heat exchanger handling hot sulphurous acid at 160–180 F under a steam pressure of 20 lb, and is using tanks lined with tellurium lead in continuous operation for strong sulphuric-acid solutions which, during the operation, reach the boiling point of the acid solution, with agitation. Steam coils, heating 66-Bé sulphuric acid at a steam pressure of 45 lb with an inside temperature of about 240 F, are said to be in use in a large Eastern plating plant, where the installation has thus far proved superior to other leads previously used.

Another severe requirement, tanks for mixing sulphuric acid in large storage-battery plants where considerable heat is evolved, with consequent expansion and contracting of the tank lining, often results in buckling and cracking of the lead. Here tellurium lead is reported to withstand conditions with less replacement than previous leads. Indications in the past two years of actual use are that this lead will extend the life of equipment in the case of the more drastic, high-temperature corrosion requirements of industry. The salvage value of lead in discarded chemical equipment is high.

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ZINC *in the* CHEMICAL INDUSTRIES

By E. A. ANDERSON

METAL SECTION, RESEARCH DIVISION, THE NEW JERSEY ZINC COMPANY, PALMERTON, PA.

THE CHEMIST thinks of zinc as a chemically active metal and not as a metal from which to construct the equipment for handling the many corrosive materials with which he deals. Attention is likely to focus on these acute corrosion problems when life of parts is measured in months, but the engineer who designs a chemical plant has many less spectacular, but perhaps equally important, corrosion problems affecting his building structure, its covering, its metal sash, its roofing and siding, its gas and water lines, its electrical conduit and other hardware, where life must be thought of in terms of years. These problems present in every building are likely to be accentuated by high humidity and corrosive fumes in chemical plants. It is in dealing with such problems that zinc plays an important rôle.

The use for certain parts of industrial structures of zinc or zinc-alloy sheet or of zinc-alloy die castings will be discussed later but steel is the predominant structural material and it is in its rôle of protector of steel that zinc is most widely used. In 1934,[1] more than 150,000 tons of zinc, or 42 per cent of the total production, was used in the production of zinc coatings on steel.

In spite of the familiarity with zinc coatings that might be presupposed from the widespread use that these figures indicate, the facts important to the most advantageous use of zinc coatings are not as well or as widely understood as they should be. There is no need to apologize, therefore, for reviewing these facts.

CORROSION RESISTANCE OF ZINC IN INDUSTRIAL ATMOSPHERES

This discussion is concerned primarily with the resistance of zinc to corrosion by industrial atmospheres and to a less extent with corrosion by water. The behavior of zinc coatings, of rolled zinc, rolled-zinc alloys, and zinc-alloy die castings is so similar that whatever statements are made are equally applicable to these various forms of zinc.

In the field of corrosion accelerated tests have usually proved to be unreliable and one is therefore forced back to experience in actual use or to carefully conducted tests under service conditions and with no attempt at acceleration.

SERVICE TESTS ON ZINC COATINGS

A century's use of zinc roofing in Europe and the long continued use of zinc coatings are convincing general evidence of the favorable ratio of service life to cost when zinc is subjected to atmospheric exposure. Fortunately, there is also available an improving and steadily increasing mass of evidence based on tests under service conditions which have been conducted under impartial conditions by the American Society for Testing Materials. Attention is here called to some of their published results. Of particular interest at this point is the 1935 report of Subcommittee 8 of Committee A-5.

The tests considered in this report consist of the atmospheric exposure of galvanized sheets of a range of coating weights at two industrial locations, Altoona and Pittsburgh, Pa.; at a northern seacoast location, Sandy Hook, N. J.; at a southern seacoast location, Key West, Fla.; and in a typical rural atmosphere in the northeastern part of the country, State College, Pa.

At the present time some eight to nine years of exposure have elapsed during which no rusting has developed on any of the panels at Key West. A single rust spot has developed on one thinly coated sheet at State College, Pa. The condition of the sheets at the other locations is clearly shown in Fig. 1.

In the 1934 report[2] of this same committee are given data on the corrosion resistance of uncoated black-iron sheets in these same locations. In the humid atmosphere of Key West, Fla., 22-gage black-iron sheets rusted through in from 2.62 to 5.73 years. Even the thinnest zinc coating has prevented rusting of this material over a period of greater than eight years in this same location. In the industrial atmosphere of Pittsburgh, Pa., seven of the ten black-iron sheets failed in from 2.03 to 3.25 years, the remaining three sheets showing no failure after 7.75 years. In this location the zinc coating was removed more rapidly by the atmospheric processes but was still capable of prolonging the life of the sheets so that it was greatly in excess of their normal life in the uncoated condition.

Numerous other data may be cited without, however, adding greatly to the comprehensive data already quoted. It is of some interest, however, to cite from our own tests which show that the corrosion rate of zinc coatings in New York City is equivalent to the removal of 0.00022 in. of zinc per year of exposure.

The corrosion of unprotected iron in the outdoor atmosphere takes place with greatest rapidity under conditions of high humidity and moisture. The results already cited for tests conducted at Key West, Fla., show quite definitely that under conditions of this type, zinc coatings may be relied upon to protect iron for quite extended periods of service.

THE RELATION OF COATING THICKNESS TO SERVICE LIFE

Since a zinc coating does corrode away in time, the importance of the thickness of the coating becomes obvious at once. Early failures resulting from the use of thin coatings of zinc have caused many engineers to form a poor opinion of the life of galvanized coatings in general. In the ordinary run of galvanized iron, coatings may be obtained ranging from about 0.5 ounce per sq ft of sheet to 2 ounces per sq ft or even heavier.

The 1935 report of A.S.T.M. Committee A-5 already referred to included two curves which are reproduced in Fig. 2.

These curves show clearly that the duration of protection

[1] Metal Statistics, 1936.

Contributed to the Symposium on Corrosion-Resistant Metals in Design of Machinery and Equipment by the Iron and Steel Division for presentation at the Annual Meeting, New York, N. Y., November 30 to December 4, 1936, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

[2] Proc. A.S.T.M., vol. 34, part 1, 1934, p. 154.

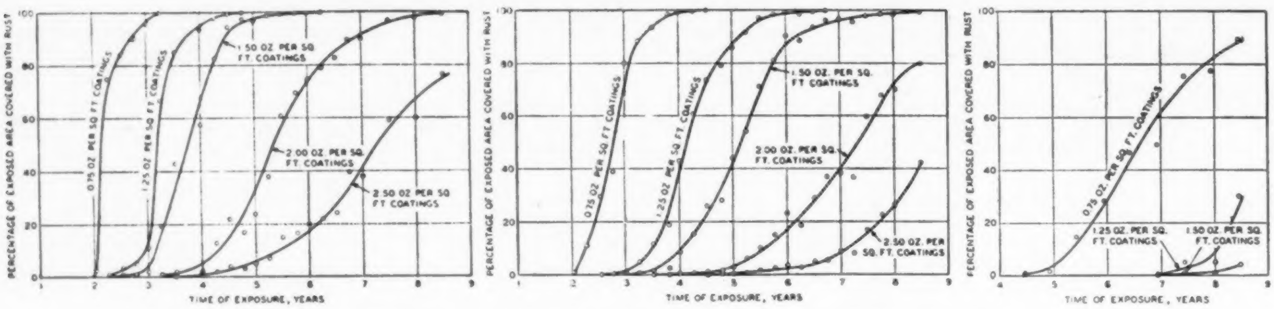

FIG. 1 PROGRESSIVE DEVELOPMENT OF RUST ON ZINC-COATED SHEETS

(Left, at Altoona, Pa.; center, at Brunot Island, Pittsburgh, Pa.; right, at Sandy Hook, N. J.)

afforded by zinc coatings is directly related to the thickness of coating; the thinner the coating, the shorter the life and the heavier the coating, the longer the life. It should be apparent that when buying any material in which the life is so directly related to the coating thickness as in these cases the thickness should be specified. The American Society for Testing Materials, through its various committees, has set up specifications for various classes of zinc-coated material to which reference should be made by the purchaser.

The problem of securing adequately coated roofing sheets has been further simplified by the efforts of the American Zinc Institute which has established a "seal of quality" under which identifying brand many leading producers market galvanized roofing sheets carrying coatings of 2 ounces per sq ft.

The same reasons which dictate the use of heavy coatings on roofing sheets apply, of course, to hardware, structural shapes, pipe, and conduit. Fortunately for the user, the usual method of applying zinc coatings by hand dipping in the case of shapes, pipe, and most hardware makes a quite satisfactory weight of coating almost inevitable. Other methods of applying zinc coatings are equally satisfactory if time is taken to apply an adequate weight of coating. Purchase on specification as to thickness of coating is the only method of insuring this.

THE GALVANIC PROTECTION OF STEEL

In discussing zinc coatings up to this point we have considered only the protection due to the inherently greater corrosion resistance of zinc as compared to steel. Beyond this, zinc offers particular advantages as a protective coating for steel. The strong tendency of zinc to wet and alloy with iron is responsible for the continuity and freedom from pinholes which characterize galvanized coatings and the high degree of mechanical protection to the steel surface in preventing access of moisture to it. But in addition, when the zinc coating is removed by abrasion, wear, or slow corrosion, the zinc becomes the anode in an electrolytic couple which prevents rusting of the steel over an area adjacent to the coating. The extent and importance of this effect is perhaps best shown in the data compiled by Subcommittee 8 of Committee B-3 of the American Society for Testing Materials in their report for the year 1935.[3]

Fig. 3 is reproduced from this report. The solid horizontal lines represent the extent of corrosion of iron exposed alone. The heights of the vertical columns represent the corrosion of iron when exposed in contact with the metals noted on these columns. The very small amount of corrosion of iron in contact with zinc is clearly evident.

While the evidence that zinc galvanically protects steel is unmistakably clear, misconceptions have arisen as to the distance from the zinc surface over which such protection may extend. Since the effect is electrolytic and depends on the conduction of current through the film of moisture connecting the iron and zinc surfaces, the conductivity of this film becomes the controlling factor. Practically all moisture contains dissolved gases and salts which improve its conductivity to the point where protection may be obtained over a distance amounting, in the case of seashore atmospheres, to as much as $^1/_4$ in. Advantage is taken of this effect in the frequent use of galvanized coatings on marine hardware.

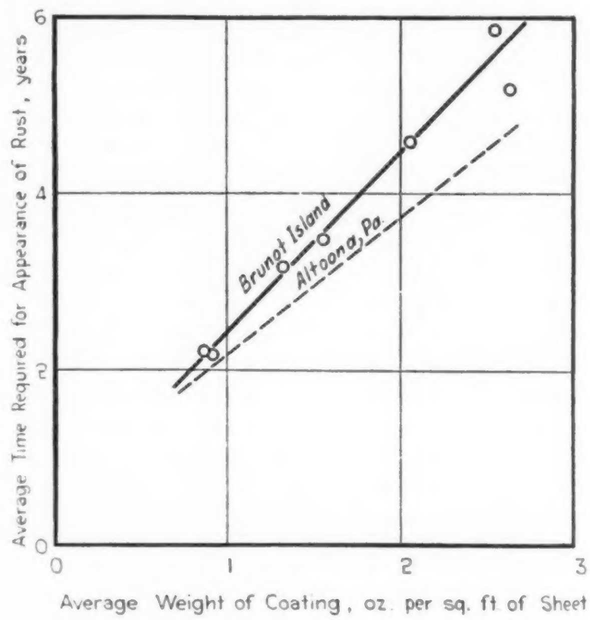

FIG. 2 RELATIONSHIP BETWEEN WEIGHT OF COATING AND TIME AT WHICH RUST APPEARS ON SPECIMENS EXPOSED AT BRUNOT ISLAND, PITTSBURGH, PA.

(Altoona relationship shown for reference.)

While the present discussion concerns zinc in the form of a coating applied to steel, other applications involving galvanic protection should not be neglected. Sacrificial protection of other metals is frequently obtained at the expense of detachable slabs of zinc. This method is used in the protection of the iron tubing and castings in oil wells, of propeller-shaft housings, and rudder bearings below the water level on small ships, and of condensers for use with sea water.

Zinc plates have been used to protect steel in marine boilers. Bannister,[4] however, points out that while the protection af-

[3] Proc. A.S.T.M., vol. 35, part 1, 1935, p. 167.

[4] "The Protective Action of Zinc Plates in Boilers," by C. O. Bannister, *Metal Industry* (London), vol. 41, 1932, pp. 441–443, 467–470.

forded by zinc is real, the effect is not due to electrolytic action but to the fact that zinc uses up the oxygen present in the water and thereby renders it unavailable for the corrosion of iron.

Some consideration has been given to the protection of underground pipe lines against soil corrosion by the use of zinc anodes spaced at frequent intervals along the pipe and connected by insulated wire to the pipe, the circuit being completed through the moist earth. It is understood that experiments along these lines are under way but no experimental evidence of successful corrosion prevention by this means is as yet available.

CORROSION RESISTANCE OF ZINC IN WATER

Zinc and zinc-coated materials are not strongly resistant to the attack of strong acids and alkalies and are seldom used in contact with these liquids. They are, however, quite resistant

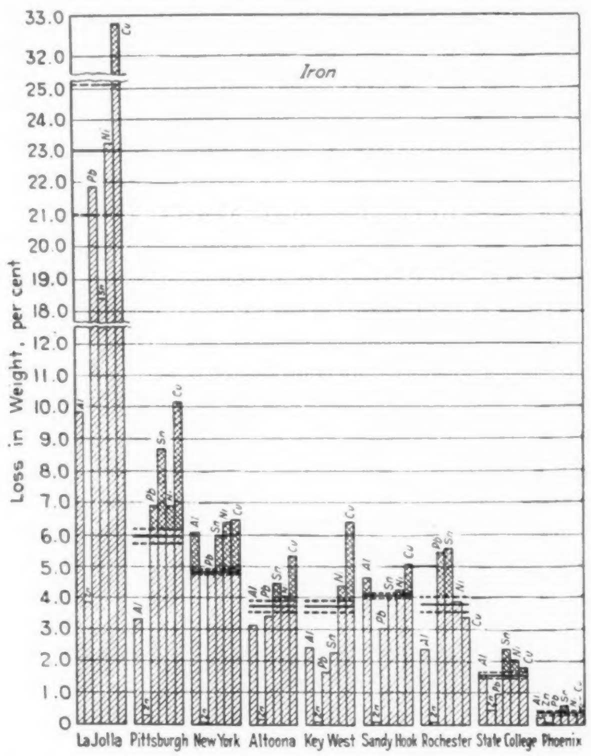

FIG. 3 GALVANIC-COUPLE CORROSION—PERCENTAGE LOSS IN WEIGHT OF IRON DISKS AFTER THREE YEARS OF EXPOSURE

to the attack of water and weak alkalies and have been used for a great many years in the construction of containers and pipes for conveying such materials. The corrosion of zinc by water is a complex subject involving a large number of variables and it is unsafe to attempt any general statements with regard to corrosion in this medium. It may well be pointed out, however, that the particular conditions of oxygen content which create the most rapid corrosion of zinc will tend to do the same with steel, and zinc retains its relative advantage over steel. Hence, it is often advantageous to use a zinc coating even where its expected life is relatively short.

Zinc offers its greatest resistance to corrosion by water in the weakly alkaline range. Roetheli, Cox, and Littreal,[5] state that the corrosion of zinc by aerated distilled water is at a minimum in the pH region 6–8 to 12. Independent experiments[6] under somewhat different experimental conditions have confirmed, in general, the fact that the corrosion of zinc by water becomes very slow in this general pH region. Sale and Badger[7] cite data showing that the pH of water in which zinc is exposed rises slowly and eventually reaches a value between 8 and 9. In other words, the corrosion of zinc by water tends to displace the pH of the water in the direction of minimum attack.

The common use of zinc-coated pipes and tanks for the conveyance and storage of water gives practical support to the laboratory data cited here.

Conditions may arise in connection with specific service exposures in contact with water where the presence of corrosion products may be undesirable or where, for reasons specific to the application, the normal corrosion rate of zinc is unduly accelerated. In closed circuits where the same water is recirculated advantage may be taken of the retarding effect of certain inhibitors such as sodium dichromate. A newly developed patented process[8] which forms an inhibiting film on the zinc surface may be used to advantage in many cases.

SPECIFIC APPLICATION OF ZINC COATINGS

The use of zinc coatings is accepted practice for certain uses. Attention might profitably be given to taking advantage of this protection in many other ways, some of which we shall endeavor to point out.

In dry locations, paint may be the most desirable protection for interior steel work, but where condensation occurs as is often the case in buildings housing wet chemical processes, galvanizing of the structural work in new installations is often worth while. Where painting is hazardous or unduly expensive, inside or out, galvanizing is particularly advantageous. Transmission towers offer a good example. It is worth bearing in mind that even though the zinc coating may not have an indefinite life under a given set of conditions it will ultimately serve as an excellent base for painting if carried out before any extensive rusting occurs. The galvanic protection of even a small amount of remaining zinc under the paint will prevent rusting by moisture which penetrates the film.

This same line of argument applies with equal force to all types of iron hardware, pipe, conduit and fittings, chain, and steel wire. It is scarcely necessary to call attention to the universal use of zinc coating for telegraph wire, fence wire, and suspension-bridge cables.

A typical illustration of the value of zinc coatings is shown in Fig. 4. The galvanized pipe, uncoated iron elbow, and bronze valve have been in service five years in a chemical plant where the atmosphere is high in humidity and where traces of hydrogen sulphide are present. The elbow is covered with scaly rust and the bronze valve is coated with a heavy greenish black scale of corrosion products. It is of particular interest to point out the deep corrosion of the portion of the pipe where the unprotected threads were not enclosed by the fitting. This represents the corrosion which would have taken place on the entire pipe had it not been zinc-coated. Needless to add, in such a location the threads should be protected at the time of installation by an application of zinc-dust paint.

[5] "Effect of pH on the Corrosion Products and Corrosion Rate of Zinc in Oxygenated Aqueous Solutions," by B. E. Roetheli, G. E. Cox, and W. B. Littreal, *Metals and Alloys*, vol. 3, 1932, pp. 73–76.

[6] Unpublished data, The New Jersey Zinc Company, Palmerton, Pa.

[7] "Contamination of Beverages and Other Foods With Zinc," by J. W. Sale and C. H. Badger, *Industrial and Engineering Chemistry*, vol. 16, 1924, p. 164.

[8] The New Jersey Zinc Company's Cronak process, U. S. Pat. No. 2,035,380.

Steel sash offers another example of a place where moisture can penetrate into crevices which cannot be reached and protected by paint. Zinc coating is a highly profitable initial investment.

In many chemical plants contamination of the product is a serious factor. One frequent source of contamination is iron rust scaling off from unprotected pipes and hangers. The galvanizing of all such parts eliminates this source of trouble.

In ending the discussion of zinc coatings we must draw attention to one of the most important and most neglected applications. In many places, timber construction is desirable for economic reasons or because atmospheric conditions are too severe for any metallic construction. The life of wooden construction is usually limited by the life of the metal fastening. To take a homely illustration, a fence erected with black-iron nails fails by rusting of the nails, but before the nails have rusted off, the rust has expanded the nail hole, attracting and holding moisture and rotting the wood around it. The fence is repaired by renailing and the process repeated until the sound wood available for renailing is gone. Galvanized nails represent a negligible increase in the initial cost and enormously extend the maintenance-free, and the total, life. Except where it is known that the wood will remain permanently dry, any fastening not zinc-coated is "penny wise pound foolish."

CORRUGATED ROOFING MATERIALS

In the foregoing discussion it has been made clear that an adequate zinc coating on the surface of steel sheets will last for many years in most locations. There is a distinct advantage to be derived, however, from the use of solid zinc sheets having the same general corrosion resistance, in that the ultimate painting which is required with the steel sheets is avoided. Quite a few years ago an attempt was made to take advantage of this additional durability on the part of solid zinc sheets by using them in corrugated form in the roofing and siding of industrial buildings. It was soon found, however, that when placed on purlins spaced according to standard galvanized-iron practice, the sheets tended to sag.

Extensive experiments[9] were carried out in which the maximum safe spans were determined for the ordinary type of rolled prime western zinc in a variety of gages. In Table 1 will be found data on the subject.

While some use was made of corrugated zinc with these spacings, it was realized at a very early stage that the necessity of increasing the number of steel supports in order to bring the spacings below the permissible maxima involved an extra expenditure in the original construction that was difficult for the design engineer to accept. Considerable work has been done since that time to develop zinc alloys having sufficient resistance to creep to permit their application on standard steel purlin spacings. Table 2 gives the spacings which have been found possible with a zinc-alloy sheet known as Zilloy.[10] These spacings fall within the range commonly used in ordinary steel building construction.

TABLE 1 MAXIMUM SAFE SPANS FOR UNALLOYED CORRUGATED ZINC

Gage	Thickness, in.	Section profile, in.	Safe span in. 40-lb load[a]
13	0.032	$^7/_8 \times 2^1/_2$	34
14	0.036	$^7/_8 \times 2^1/_2$	$35^1/_2$
15	0.040	$^7/_8 \times 2^1/_2$	$37^1/_2$
16	0.045	$^7/_8 \times 2^1/_2$	39

[a] Roof load, pounds per square foot.

TABLE 2 MAXIMUM SAFE SPANS FOR ALLOYED ZINC (ZILLOY)

Gage	Thickness, in.	Section profile, in.	Safe span in. 40-lb load
13	0.032	$^7/_8 \times 2^1/_2$	48
14	0.036	$^7/_8 \times 2^1/_2$	51
15	0.040	$^7/_8 \times 2^1/_2$	54
16	0.045	$^7/_8 \times 2^1/_2$	57
12	0.028	$1 \times 2^1/_2$	50.5
13	0.032	$1 \times 2^1/_2$	54
14	0.036	$1 \times 2^1/_2$	57
15	0.040	$1 \times 2^1/_2$	60
16	0.045	$1 \times 2^1/_2$	63

[9] "Some Practical Aspects of Creep in Zinc," by W. M. Peirce and E. A. Anderson, Trans. A.I.M.E., Inst. Met. Div., vol. 83, 1929, p. 560.

[10] Registered United States Patent Office.

FIG. 4 GALVANIZED PIPE, UNCOATED IRON ELBOW, AND BRONZE VALVE AFTER FIVE YEARS OF SERVICE IN A CHEMICAL PLANT WITH HIGH-HUMIDITY, HYDROGEN-SULPHIDE ATMOSPHERE

CAST IRON *in* CHEMICAL EQUIPMENT[1]

By H. L. MAXWELL

E. I. DU PONT DE NEMOURS & CO., WILMINGTON, DEL.

CAST IRON has been used in chemical-process equipment in large tonnages over a longer period of time than any other material of construction, with the possible exception of wrought iron. Its ready availability (cast-iron foundries are found everywhere) and its low cost ($3^1/_2$ to 6 cents per pound) present the two main reasons for its use in general machinery and chemical equipment.

Until about 15 years ago, cast iron was considered a low-strength material of rather indefinite quality. During the last two decades cast iron has been made the subject of many studies. Its quality has been improved by refinements in foundry practice, by alteration of the basic ratios of carbon and silicon, and, more recently, by the addition of alloying elements, such as nickel, chromium, molybdenum, and copper. Cast iron in its various modified forms has been widely used in chemical manufacturing equipment, and its further application in new processes depends only upon the recognition of properties it is possible to develop by the use of alloying elements.

The primary object of most chemical developments is to produce a commercially salable product at a profit, and to do this safely, with a reasonable degree of permanence as regards the equipment used. To attain this objective it has been necessary in many cases to improve a low-cost material to the point where the product made in equipment constructed of it has more than met all the requirements with regard to quality, such as purity and color.

The present paper will review the ways in which older types of cast iron have been used in chemical-process equipment and how, following failure in service, some of the compositions have been improved to provide materials of construction for equipment in which chemical products meeting all requirements as to quality have been produced at relatively low cost.

GRAY CAST IRON

The term "gray cast iron" covers a wide latitude of compositions of which the following composition ranges may be taken as typical:

Total carbon, per cent	2.6–3.70
Silicon, per cent	0.75–2.80
Manganese, per cent	0.60–0.90
Phosphorus, per cent	0.60 max
Sulphur, per cent	0.04–0.1

Unfortunately, this wide range of composition is still typical of some of the specifications laid down to foundries manufacturing cast-iron equipment.

It is literally true that a given foundry can furnish equipment well within these specifications and yet the castings supplied may range all the way from a highly satisfactory product suitable for chemical equipment down to material of no commercial value. One of the essential points that should be brought out here is, Specify to the foundry reasonable limits of composition that you know by experience are suited to your operation and, having done that, insist that you get what you specify.

A recognized disadvantage of ordinary coarse-grained cast iron, particularly when it is exposed to corrosive chemicals, is that the large areas of graphite permit an infiltration of the corrosive constituents into the body of the casting and thereby contribute to early failure. A striking example of this type of failure was found in cast-iron hearths of a Herreshoff furnace used to calcine a paste of spent lime and adsorbed caustic. Two reactions had taken place: (1) The caustic had gained access through the coarse graphite flakes to approximately 30 per cent of the thickness of the hearth casting, causing cracking, and (2) the entire surface of the metal had been attacked, owing to the action of free caustic on the silicon in the cast iron.

This type of failure is found most frequently in caustic evaporation pots, sodium-sulphide evaporators, and similar equipment, where the metal container is exposed to large amounts of hot caustic. Figs. 1 and 2 show the effect of caustic attack on an ordinary coarse-grained cast iron when magnified 100 and 200 diameters, respectively. It is noted that the caustic has advanced into the body of the metal, making its way along the coarse graphite tendrils.

Destructive attack of this kind can be reduced by lowering the silicon content to a point where there is just sufficient silicon to graphitize the excess carbide and leave an eutectoid matrix of lamellar pearlite. Cast iron with this type of microstructure shows a twofold improvement; the graphite is more finely divided and hence more resistant to chemical attack, and the matrix has not only higher strength but is more nearly continuous as well.

The type of deterioration illustrated in Figs. 1 and 2, as a result of caustic attack, can be avoided or at least greatly reduced by the use of one or two classes of materials now being successfully used in such applications. One of these is Lyncast low-silicon cast iron, of which the composition is approximately: Carbon 3.45, silicon 0.75, manganese 0.30, phosphorus 0.10, and sulphur 0.08 per cent. The increased resistance of this material to caustic and related chemical attack is due largely to the lower silicon content as compared to ordinary cast iron.

By virtue of the low silicon content, the metal is fine-grained and less pervious to the infiltration of caustic or chemical salts. A typical photomicrograph of Lyncast low-silicon cast iron is shown in Fig. 3 at a magnification of 200 diameters. Note

[1] Based, in part, upon the paper presented by the American Institute of Chemical Engineers to the Chemical Engineering Congress of the World Power Conference, held in London, England, June 22–27, 1936, and to be included in the Transactions of the Congress, to be published in London shortly.

Contributed to the Symposium on Corrosion-Resistant Metals in Design of Machinery and Equipment by the Iron and Steel Division for presentation at the Annual Meeting, New York, N. Y., November 30 to December 4, 1936, of The American Society of Mechanical Engineers.

that the graphite flakes are small and that the matrix is of a uniform eutectoid structure which combines mechanical strength with corrosion resistance.

LOW-ALLOY CAST IRON

Low-alloy cast irons, widely used for caustic service, may be either a straight nickel cast iron or a chrome-nickel iron of low silicon content, the former being usually preferred. Compositions recommended by the International Nickel Company are as follows:

FIG. 1 CAUSTIC ATTACK ON ORDINARY GRAY CAST IRON—×100

	1	2
Carbon, per cent	3.50	3.30
Silicon, per cent	0.50	0.70
Nickel, per cent	2.00	1.50
Chromium, per cent	0–0.30	0.60
Manganese, per cent	0.50	0.50

A particular application where a low-alloy cast-iron composition, selected because of its low growth, showed definite economic advantage over ordinary cast iron, may be of interest. Autoclave inserts, 11 ft 4 in. by 3 ft 9 in. and $1^1/_4$ in. thick, weighing 6700 lb, were made of ordinary gray cast iron and operated at 720 F. The early failure of these parts prompted a study of the problem to determine a more economical material of construction. The condition and nature of the metal failures indicated that the fractures resulted from the combined effect of expansion or growth, and also from coarseness of structure in the metal wall. The relatively large weight of the insert and also the conditions of corrosion eliminated high-alloy materials, such as stainless steel, from consideration on account of cost. The best probability lay in the use of high-quality low-alloy cast iron, and the following composition was recommended: Carbon 3.20–3.40, silicon 1.00–1.25, nickel 1.00–1.25, chromium 0.40–0.50, sulphur 0.08 (max), phosphorus 0.25 (max), and manganese 0.80 per cent.

It will be noted in the foregoing analysis that the percentage of nickel is roughly $2^1/_2$ to 3 times the percentage of chromium and, further, that since the silicon and nickel are both graphitizing in effect, the silicon is lowered from the normal as far as possible. The purpose of this is to equalize the two opposing reactions affecting the stability of the combined carbon. Frequently, silicon may be reduced in the absence of chromium by an amount approximately equal to half of the nickel added, and greater thermal stability may be expected owing to the greater solubility for carbon that nickel possesses and that is accompanied by an inherent resistance to oxidation.

In following these castings through the foundry it was found desirable to add 25 per cent of heavy steel scrap in order to bring the silicon and sulphur of the pig iron within the proper limits for alloy conditions.

The low-alloy cast-iron vessels have now been in service approximately two years and have shown improvement in operating life. The initial cost of the low-alloy iron was 4.5 cents per lb, as compared with 3.75 cents for the plain cast iron formerly used. This 20 per cent increase in first cost is too frequently the reason why alloy iron is not used. The increase in cost is small as compared with the savings gained from longer life of the equipment in the present instance, where the life increases by a ratio six to one. After debiting the increase in first cost of the low-alloy castings, the maintenance has been reduced from $1070 to $225 per unit per year through the use of low-alloy cast iron.

FIG. 2 CAUSTIC ATTACK ON ORDINARY GRAY CAST IRON—×200

An example of growth in ordinary cast iron was recently noted in steam turbines which had been operated satisfactorily for 10 to 12 years. Later the operating conditions were altered so that the pressure was 170 lb per sq in. and the operating temperature approximately 500 F. Following this change it was found that the cast iron was growing at the rate of 0.017 in. per year. The use of an alloy cast iron in the original body castings would have eliminated this difficulty. Cast steel was, as a matter of safety, used in the replacements.

WEAR-RESISTANT CAST IRON

Cast iron of another kind is required for use in chemical-manufacturing equipment in which the metal is exposed to abrasive wear. The pearlitic cast irons described earlier will wear down to a smooth surface, which, on account of the large amount of graphite and the absence of free carbide, will take a lubricant effectively and develop a wear-resistant surface that will be maintained through years of service. This is the type of wear encountered in cast-iron piston rings and the cylinder blocks of automotive engines. Here the wear resistance may be improved by the addition of nickel and chromium, metals which improve such physical qualities as soundness, and at the same time result in better distribution and size of the graphite flakes which are so essential to securing the longest service from lubricated moving parts. This type of wear is distinct from the abrasive wear which is met with in chemical equipment, such as grinding mills, agitators, bucket elevators, and hoppers.

For applications where resistance to abrasion is an important factor, hard cast irons are extremely useful. Though it is generally recognized that a pearlitic iron is more resistant to wear than a ferritic iron, it is necessary to obtain a harder

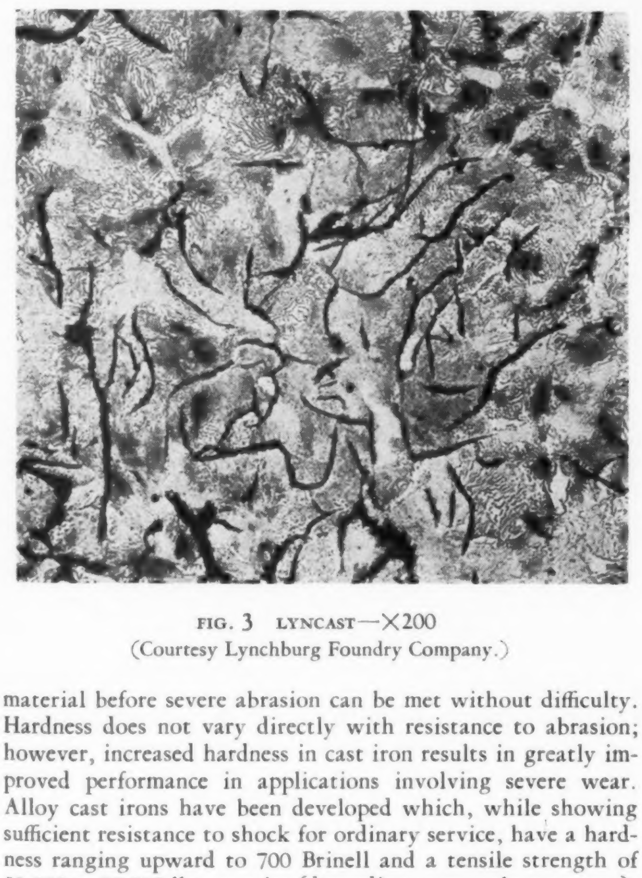

FIG. 3 LYNCAST—×200
(Courtesy Lynchburg Foundry Company.)

material before severe abrasion can be met without difficulty. Hardness does not vary directly with resistance to abrasion; however, increased hardness in cast iron results in greatly improved performance in applications involving severe wear. Alloy cast irons have been developed which, while showing sufficient resistance to shock for ordinary service, have a hardness ranging upward to 700 Brinell and a tensile strength of 55,000 to 80,000 lb per sq in. (depending upon carbon content), which is 55 to 65 per cent greater than the tensile strength of white cast iron without alloy additions. Two martensitic cast irons of this class are Ni-Hard and Diamite. The composition of Ni-Hard lies within the following range:

Carbon, per cent	2.75–3.6
Nickel, per cent	4.40–4.6
Chromium, per cent	1.40–1.6
Silicon, per cent	0.50–1.5
Manganese, per cent	0.20–0.7

These alloys have found wide use in applications such as pump casings, machinery for handling ashes or sand, ash-sluice liners, dredging equipment, grinding disks, and conveyor screw flights, and have replaced white cast iron in many instances.

A typical photograph of a metal for resistance to abrasive wear is shown in Fig. 4, magnification 200 diameters. The white areas are free carbide and are set in a matrix of fine-grained martensite. In general, it may be said that the degree

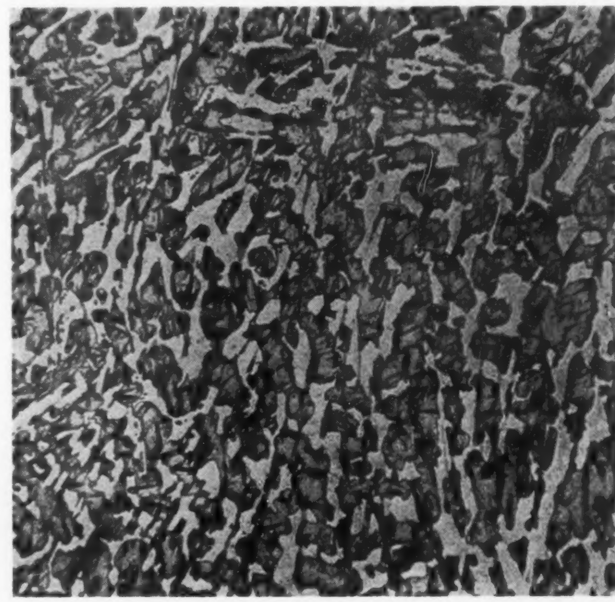

FIG. 4 METAL CONTAINING FREE CARBIDE FOR ABRASION-RESISTANT SERVICE—×200

of resistance to abrasion is proportional to the amount of free carbide present in a cast iron of this type.

It may be understood from the foregoing that in the majority of cases where severe abrasive wear is encountered it would be economical to make the alloy additions in the foundry at the necessary added cost. It should not be forgotten, however, that cooling rates in the foundry may develop sufficient hardness in castings for service in certain chemical equipment, and that it would not be economical to pay for the addition of chromium and nickel. One illustration from plant experience will demonstrate this point.

In a grinding mill the original lining plates, 5 ft by 10 ft long, gave about 500 days' service. The mill lining supplied by the manufacturer as a replacement gave only about 75 days' service before failure. Chemical analyses of these two materials were as follows:

	Original	Replacement
Combined carbon, per cent	3.16	0.49
Graphitic carbon, per cent	0.11	2.94
Manganese, per cent	0.45	0.65
Phosphorus, per cent	0.168	0.149
Sulphur, per cent	0.126	0.101
Silicon, per cent	0.48	1.13
Nickel, per cent	0.31	0.02
Chromium, per cent	0.435	0.165

The hard cast-iron material furnished in the original mill had been made by chilling in the mold. It will be noted that the chemical analyses of the iron furnished with the mill and of that furnished as replacement are similar, except that in the latter case the silicon is higher and the chromium and nickel

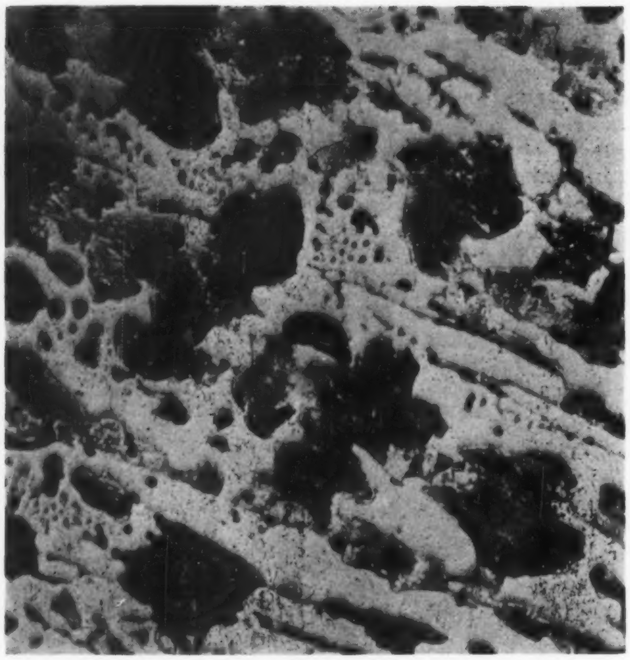

FIG. 5 STRUCTURE OF ORIGINAL CASTING—X200 (Hardness 415 Brinell.)

FIG. 6 STRUCTURE OF REPLACEMENT CASTING—X200 (Hardness 179 Brinell.)

lower. These small changes in composition demonstrate how important rates of cooling and composition are in relation to obtaining economical life from cast-iron equipment for abrasive service.

Photomicrographs of the original and the replacement castings are shown in Figs. 5 and 6, respectively. Note in the former the large areas of wear-resistant free carbide that were responsible for prolonged life in ore-grinding service, and the relative absence of free carbide among the soft graphite flakes in the latter installation. In most respects the chemical compositions of the two shipments of castings are similar, but a marked difference in plant service was found on account of the increased hardness due to chilling of the original castings.

There are also certain applications in chemical equipment where a cast metal must be resistant to abrasion and corrosion at elevated temperatures. Equipment for roasting sulphide ores, including hearths and agitator devices to keep the ore bed mixed and in contact with oxidizing atmospheres, are of this type. Alloy cast iron containing 2 per cent nickel and up to 0.75 per cent chromium have been used, as have been also cast irons of higher hardness and scale resistance, as, for instance, iron castings containing 4 to 5 per cent silicon and 2 per cent chromium. This latter material is quite resistant to scaling in sulphurous atmospheres. It is, however, not resistant to shock and frequently breaks if used in moving furnace parts. In some equipment applications in which sulphurous atmospheres at temperatures of 900 C (1652 F) are evolved it is economical to employ higher-alloy materials. A 25 to 28 per cent chromium with or without 3 per cent nickel and carbon at about 1 per cent have been used where severe abrasion is encountered at high temperatures but where there is no severe shock. If shock is present, the chromium and nickel would remain the same and the carbon be lowered to 0.40 per cent in order to increase shock resistance. Although this latter metal is in the strictest sense not a cast iron, it fills out the range of abrasion and heat-resistant metals for service in borderline applications where cast iron may not be economical.

For purposes not requiring such a high degree of resistance to wear, straight chromium additions up to 1.0 to 1.5 per cent, or low nickel-chromium additions in which the nickel-chromium ratio may be reduced to as low as $^1/_2$ to 1 in special cases, together with balanced variations in silicon, are frequently helpful. Nickel, when present alone, tends to combine with and harden the pearlite matrix, which, as the nickel is increased to 3.0 per cent, is transformed into sorbite, and even to martensite with amounts above 5.0 per cent. Free carbide is reduced or eliminated at the same time. Molybdenum additions up to 1.5 per cent are beneficial. A test was made in which 30 gear blanks were prepared under identical conditions; 15 of regular cast iron and 15 of the same iron with 0.67 per cent molybdenum. The Brinell hardness of the molybdenum iron was 231 on the side of the iron and 216 on the face of the rim, as compared to 211 and 192 for regular cast iron. No appreciable effect on machinability was noted.

It may be desired to obtain the maximum possible machinable hardness by direct alloying. Attention is called to the fact that the composition must be adjusted to correspond to the thickness of the sections involved. Thin sections are hardened to a greater degree than heavy sections by the same alloy additions. For instance, a cast iron containing 3.35 per cent carbon and 1.25 per cent silicon showed a hardness of 250 Brinell in a $^1/_4$-in. section with 0.75 per cent nickel and 0.25 per cent chromium. Using the same nickel-chromium ratio in a 1.25-in. section it was necessary to add 1.35 per cent nickel and 0.45 per cent chromium to attain the same hardness. Failure to take thickness of section into account has sometimes resulted in the elimination from consideration of an entirely satisfactory alloy composition. This factor is usually controlled by adjusting the silicon content rather than the total alloy addition. Low-silicon or low-carbon irons respond better to hardening if nickel-chromium additions are made. In applications where surface hardening is sufficient, treatments such as nitriding allow Brinell hardnesses up to 900 to be obtained. This type of surface is, of course, not suitable where corrosion is also a factor.

In addition to the use of chromium and nickel in cast iron for chemical equipment, high-silicon types of alloy iron have been employed with varying degrees of success.

HIGH-SILICON CAST IRON

The British Cast Iron Research Association introduced in 1928 a series of heat-treated cast irons called Silal, which covers normally a range of 4 to 6 per cent silicon, with a carbon content of from 1.6 to 2.8 per cent. These materials do not possess high strength and they are less resistant to shock than is gray cast iron. With silicon in excess of 9 per cent the difficulty of machining these high-silicon irons increases rapidly, and with silicon content between 10 and 14 per cent, in which range increased acid resistance is developed, the metal becomes brittle and unworkable except by grinding.

There is some indication that the addition of chromium to silicon cast iron markedly improves its resistance to high temperatures. It was first shown experimentally that 5 to 6 per cent silicon cast iron, with 4 per cent chromium, had good resistance to high temperatures, but this alloy had a distinct disadvantage in that it was practically impossible to machine it, even after an annealing heat-treatment. By lowering the chromium from 4 to 2 per cent and maintaining the silicon about 5 per cent, with the total carbon in the range of 3 per cent an alloy is obtained that is particularly serviceable under high temperatures, such as are encountered in calcining furnaces and similar equipment operations. Cast-iron rabble arms of roughly the foregoing composition have been in service for three years in a calcining furnace at about 820 C, with very favorable results. In describing the use of this silicon-chrome cast iron for high-temperature service, it is not meant to suggest that this material is equal in quality to the high-chrome cast materials, such, for instance, as 28 per cent chrome, 3 per cent nickel and 0.4 to 0.9 per cent carbon. These latter materials, which cost much more, have a distinct application under extremely severe conditions as, for instance, in corrosive gases above 900 C. However, silicon-chromium alloys which are available at about $5^1/_2$ to 6 cents per lb show definite economies in operation in such services as rabble arms exposed to gases of low sulphur content and operating at moderate temperatures. They are also being used to some extent in coke-oven doors and in gas-generator equipment.

High-silicon irons containing 13 to 16 per cent silicon have been used for the past 30 years where resistance to acid was required. Silicon adds little to the corrosion resistance of iron until the range of about 12 per cent silicon is reached, at which a sudden increase occurs, accompanied by a marked change in physical properties, the alloy becoming hard and brittle. American alloys known as Duriron, Tantiron, Antaciron, and Corrosiron are in the general range of 13 to 16 per cent silicon as well as Ironac, Thermisilid, and others which are produced in Europe.

There seems to be no advantage in exceeding about 16 per cent silicon. These alloys show excellent resistance to sulphuric and nitric acid, but are attacked by hydrochloric acid. Their use is limited by their susceptibility to thermal and mechanical shock. A recent development known as Durichlor contains, in addition to the silicon, about 3 to 4 per cent molybdenum and 0.25 per cent nickel. The resultant metal has about the same physical properties as Duriron, but is markedly superior in its resistance to hydrochloric acid. The corrosion penetration rate of Durichlor in boiling 20 per cent hydrochloric acid, on the basis of a 240-hr test, is approximately 0.0087 in. per month. Under the same conditions of acid concentration, temperature, and duration of test, the corresponding corrosion penetration rate on Duriron is 0.110 in. per month.

AUSTENITIC CAST IRONS

It will be recalled from an earlier paragraph, and as demonstrated by a photomicrograph, that a common cause of failure in cast-iron equipment in chemical service is the infiltration of chemicals through the coarse graphite flakes. It follows, therefore, that a good probability for increasing the life of cast iron for a given service lies in effecting a finer distribution of the graphite flakes, thereby making them less continuous and at the same time making the continuous phase, which will be predominant in amount, a single solid solution. Both of these conditions are met in the austenitic cast irons which began to be developed about 12 years ago.

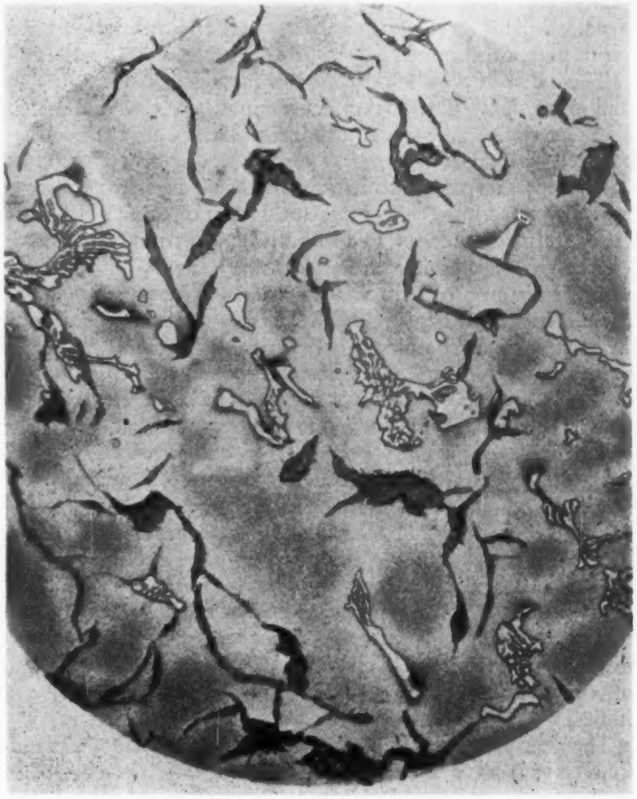

FIG. 7 NI-RESIST—×500
(Courtesy International Nickel Company.)

TABLE 1 COMPOSITION OF FOUR AUSTENITIC CAST IRONS

	Regular Ni-resist	Ni-resist (copper-free)	Nicro-silal	Causul
Nickel, per cent	12.0–15.0	15.0–20.0	18.0	18.0–21.0
Chromium, per cent	1.25– 4.0	2.50(max)	2.0	1.5
Carbon, per cent	2.75– 3.1	2.0– 2.3	1.8	2.3
Silicon, per cent	1.5 – 2.0	0.6– 2.0	6.0	2.2
Manganese, per cent	1.0 –1.50	1.0– 1.50	1.0	1.10
Copper, per cent	5.0 – 7.00	....	..	4.5
Sulphur, per cent	0.10(max)	....	..	0.05(max)

The four austenitic cast irons listed in Table 1 represent typical compositions of this class of materials. All have high nickel content, because this is essential in order to maintain austenite as a stable phase when the castings are cooled in the mould. A photomicrograph of Ni-resist is shown in Fig. 7, which demonstrates the structural properties and explains the unusual corrosion resistance toward many chemical products which is exhibited by metals of this general type. An average tensile-strength value for Ni-resist is 30,000 lb per sq in.

This general type of cast iron was described by Dawson.[2] Other austenitic cast irons have been developed since. Vanick and Merica[3] describe corrosion-resistant cast iron of the austenitic type called Ni-resist. Norbury and Morgan[4] describe the development and properties of Nicrosilal, which contains more nickel and silicon but less carbon than Ni-resist. Apart from increased nickel content, Causul differs from Ni-resist only in degree.

Although recognizing certain differences between the four austenitic irons described and their relative value in plant service, it is not considered within the scope of this paper to appraise these differences, but rather to designate where in chemical-plant service the use of austenitic alloys as a class will result in more economical operation.

The value of these cast irons lies in their resistance to heat and corrosion. The nickel, chromium, carbon, and silicon combine their influences to produce a matrix that is but little affected by oxidation at high temperatures or by acid attack at low temperatures. The resistance of these alloys to scaling at temperatures up to 950 C increases with increasing silicon content, and the tendency to grow under high temperatures decreases with decreasing carbon content.

The resistance of this class of metals to heat and chemical attack has resulted in their relatively wide application in chemical-process equipment. Rotary and reciprocating pumps, valves, pipe lines, and reaction vessels operating on sulphuric-acid mixtures, caustic, and many salts have been successfully used. Under high temperatures this material has shown excellent performance in resistance grids, coke-oven door frames, heat-treating stands in annealing furnaces, thermocouple sheaths, and similar applications. In some equipment, as, for instance, calcining and roasting furnaces operating at 400 to 600 C in the presence of sulphurous gases, the economical use of a low-alloy cast iron is problematical, particularly if the product forms a scale and adds a condition of shock to the agitating equipment. Of course, no assurance can be given that an austenitic cast iron will improve the economies of the operation, but there is a reasonable probability that it will.

The installed cost of this quality of cast iron is approximately four times that of the ordinary grade, and if the cost of installation is appreciable, the economy of using the higher quality is at once recognized. It should be pointed out clearly that too often equipment is purchased on the per-pound basis instead of the cost-installed basis. In many heavy-chemical plants, the material cost of some equipment parts is 98 per cent of the installed cost, labor representing only 2 per cent. Here, obviously, the frequency of replacement is a minor point, unless the loss of metal due to corrosion and abrasion introduces the problem of quality owing to metallic contamination of the product. Apart from this aspect, one of several low-cost materials might be used economically. In other installations equipment parts have been encountered that are exposed to corrosion and not easily accessible, such as driving and agitation mechanisms, where the installation labor cost exceeds that of the replacement part. The cost of installing equipment with superior corrosion resistance seldom exceeds that of a lower-cost, shorter-life part. Therefore, it should be better appreciated than it is that in the selection of materials greater consideration is given to the cost of installing the equipment, when further economies in production costs are made possible.

All the alloying elements listed may be varied to some degree, but there must be enough nickel present to produce a stable austenitic structure in the normal casting operation. This class of cast iron commands a higher initial price than do the conventional cast irons, but it is well worth the difference under many service conditions. Sulphuric-acid valves, sewage-disposal equipment, valves and pumps for caustic service, and pump impellers used under a wide variety of conditions show definite economies when made of cast-iron compositions high in nickel and copper.

Where there are objections to the use of an alloy containing copper, as, for instance, in dye vats containing sodium sulphide and sulphur dyes, it is possible and desirable to use the copper-free austenitic iron.

These compositions are cast and machined without difficulty, making possible their ready manipulation in the average foundry and machine shop.

The two particular properties that make austenitic cast irons useful in chemical-engineering equipment are marked resistance to a wide variety of corrosive substances and resistance to scaling and disintegration by the effects of heat.

The applications in chemical equipment where austenitic cast iron has shown marked economies are numerous. This material is almost free from the type of corrosive attack that softens the surface of ordinary cast iron and causes early failure.

By means of a simple test a fairly reliable indication whether ordinary gray-cast-iron equipment can be economically replaced by an austenitic cast iron may be obtained. It is desirable first to make an examination of the surface of the used gray-cast-iron part to determine the nature of the surface attack. If the surface is smooth, hard, and evenly corroded, it is probable that longer life would be obtained from a mottled iron casting with higher combined carbon but without alloy additions. If, on the other hand, the surface of the part is soft, indicating that the iron matrix has been dissolved, leaving the graphite unsupported, this should be taken as an indication of the fact that increased life will be obtained by a solid-solution type of matrix. This improvement is found in the austenitic alloys.

Cast-iron pump bodies, impellers, and valves in weak-acid service (e.g., saturated solutions of carbon dioxide and hydrogen sulphide under pressure, or weak organic and inorganic acids) develop a layer of soft graphitic material on the exposed surfaces. This carbon residue is soft, can be readily cut with a pen-knife, and on long exposure will reach a thickness of $^3/_8$ in. In applications of this particular kind, the use of low-alloy cast iron, containing, for instance, up to 2 per cent total alloy content, is rarely, if ever, effective in reducing maintenance costs. These are applications for austenitic iron, and, if any further increase in initial cost is justified, consideration should next be given to castings of 17 to 18 per cent chromium with 0.35 per cent carbon, or nickel-chrome low-carbon alloys (18–35 per cent Ni, 15–30 per cent Cr) which are classified as alloy steels rather than as alloy irons.

A series of scaling tests was made on a variety of low-alloy cast irons and on some metals including higher alloy content up to the austenitic range. The specimens were disks 2 in. by $^1/_4$ in. The tests were made at 550, 750, and 950 C, at

(*Continued on page 845*)

[2] "Non-Magnetic Cast Iron," by S. E. Dawson, *Foundry Trade Journal*, vol. 29, 1924, pp. 439–443.

[3] "Corrosion and Heat-Resistant Nickel-Copper-Chromium Cast Iron," by J. S. Vanick and P. D. Merica, Trans. American Society for Steel Treating, vol. 18, 1930, pp. 923–942.

[4] "The Effect of Carbon and Silicon on the Growth and Scaling of Gray Cast Iron," A. L. Norbury and E. Morgan, *Journal of the Iron and Steel Institute*, vol. 23, 1931, p. 413. Also: "Manganese-Silicon and Nickel-Silicon Cast Iron," Ibid., vol. 125, 1932, p. 393. Also: "Nickel-Chromium-Silicon Cast Iron," Ibid., vol. 126, 1932, p. 301.

COPPER *and* COPPER-BASE ALLOYS

In the Construction of Corrosion-Resisting Equipment and Structures

By R. A. WILKINS

THE REVERE COPPER AND BRASS INC.

COPPER AND copper-base alloys have been used extensively in industry for centuries.

In general, the physical and chemical properties of these materials are well known and much published information pertaining to their resistance to corrosion is readily available to the engineer. Most of the available information on corrosion resistance, however, is based on laboratory observations. In the laboratory it is a relatively simple matter to determine the resistance of a given metal or alloy to the corrosive attack of a specific reagent under stated conditions of temperature and concentration. When in a particular instance published information is not available, laboratory data of this fundamental and important type can usually be readily developed.

In the field, however, it does not suffice to consider only the chemical action of a given corrosive agent on a specific metal or alloy. It is necessary also to consider the influence of numerous other possible factors affecting corrosion, which may be incident to industrial application of that metal or alloy. Impurities present in either the agent or metal are frequently sources of destructive corrosion of a metal that normally would be unaffected, if it or the agent were pure. The effect of atmospheric oxygen in conjunction with the agent, the conditions existing by reason of agitation or flow of fluids, and many other secondary factors, must be taken into account by the engineer in selecting a suitable corrosion-resisting material of construction. In addition, the physical condition and the physical properties of the metal, and even the methods employed in its fabrication, must be considered, for all these are factors which may affect its resistance to corrosion.

Furthermore, the selection of a suitable corrosion-resisting material for an industrial use demands careful consideration of many economic factors. The engineer in any ordinary case obviously seeks the material which will give him the maximum service per dollar of investment, and he should balance material costs, construction costs, replacement and shutdown costs in an effort to determine which available material of construction will, in a given application, show him the maximum economic advantage.

In many industrial applications, copper and its numerous alloys are substantially immune to the corrosive action of the media to which they are exposed, and will last indefinitely. There are other industrial applications where these metals should give an indefinitely extended service, but where failure because of corrosion may result by reasons of unsuitable design and improper mechanical construction. Further, there are many situations in which no commercial metal will have an indefinitely long life, but in which copper and its alloys possess a combination of physical and chemical properties which render them the best obtainable materials, when all factors, including ultimate costs, are taken into consideration. It is particularly true that design and operating factors must be given the closest attention in connection with applications of these two latter kinds, and, commonly, careful control of such factors, when possible, will result in successful and satisfactory performance in many instances where rapid deterioration of the metal might otherwise occur.

The foregoing considerations are not peculiar to copper and its alloys, but the same considerations, of course, are equally pertinent with respect to ferrous and other metals and materials subject to corrosion.

It is not the purpose of this paper to present an extensive tabulation of existing information on the resistance of copper and its alloys to a multiplicity of corrosive media. It aims rather to present the characteristic corrosion-resisting properties and the fundamental physical properties of the metals in question, and to direct the attention of the engineer to those easily overlooked factors which so often determine the effectiveness of a given cuprous material when used in a structure or apparatus designed to resist corrosion. In addition, it will discuss certain familiar applications of these materials, and those factors incident to such applications, which the engineer must take into account, if he is to secure maximum effectiveness of the corrosion-resisting properties of the materials. An understanding of these factors will aid his consideration of the problems arising in connection with analogous applications.

There are many copper-base alloys of industrial significance and, from the standpoint of the engineer, the materials under consideration in this discussion can be naturally classified in the following groups:

1 Copper.

2 The brasses, including not only the binary copper-zinc alloys, but those alloys as modified by the addition of small percentages of other constituents.

3 The copper-silicon alloys as modified in commercial practice by additional constituents.

4 The bronzes or copper-tin alloys and the aluminum bronzes.

5 Cupronickel and the nickel silvers.

6 Those alloys used primarily for the production of castings and not normally susceptible of fabrication through hot-or-cold working.

These materials, as so grouped, will now be discussed from the standpoint of the engineer interested in the design and construction of corrosion-resisting apparatus and equipment.

COPPER

Copper is commercially available in a high degree of purity as electrolytic copper. In the United States this form of copper constitutes by far the bulk of that metal used in commercial products. For special purposes, however, there are available modified forms of copper, such as the arsenical coppers, the argentiferous coppers, phosphor deoxidized copper, oxygen-free copper, and fire-refined copper.

The fundamental physical properties of these various com-

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TABLE 1 PHYSICAL PROPERTIES OF THE COPPERS

Material	Tensile strength, lb per sq in. Hard	Tensile strength, lb per sq in. Soft	Elastic limit, lb per sq in. Hard	Elastic limit, lb per sq in. Soft	Elongation, per cent Hard	Elongation, per cent Soft	Rockwell F hardness Hard	Rockwell F hardness Soft	Melting point, C	Density, lb per cu in.	Coefficient of expansion	Electrical conductivity[1]	Thermal conductivity[2]	Modulus of elasticity, lb per sq in.
Electrolytic copper	55,000	30,000	50,000	0	5	50	95	20	1083[a]	0.322	0.0000177[c]	101.0	0.923[c]	16×10^6
Phosphorized copper..........	58,000	34,000	55,000	0	5	50	98	23	1083	0.322	0.0000177	74.7[d]	0.727[d]	16×10^6
Arsenical copper..	60,000	35,000	56,000	6000	5	45	98	23	1083	0.322	0.0000177	50.0[b]	0.398[c]	16×10^6
Argentiferous copper (4 to 12 oz silver per ton)..	55,000	30,000	50,000	0	5	50	95	20	1083	0.322	0.0000177	101[d]	0.923[c]	16×10^6

[1] Per cent of International Annealed Copper Standard.
[2] Cal per sq cm per cm per sec per C at 20 C.
[a] Circular No. 73, U. S. Bureau of Standards.
[b] Scientific Paper No. 410, U. S. Bureau of Standards.
[c] "Arsenical and Argentiferous Copper," J. L. Gregg.
[d] "Thermal and Electrical Conductivities of Copper Alloys," C. S. Smith and E. W. Palmer, A.I.M.E. Tech., Bull. No. 648, 1935.

mercial kinds of copper are shown in Table 1. Except that arsenical coppers seem to retain their strength better at elevated temperatures than the others (1, 2, 3, 4, 5, 6),[1] the chemical properties of these metals influencing their resistance to corrosion are so generally similar as to render separate discussion of each of them unnecessary.

VARIOUS FORMS OF COPPER

Commercial argentiferous copper contains up to approximately 12 ounces of silver per ton, and is used principally in applications where fabricated articles are to be assembled by a soldering operation. The silver content raises the softening temperature of the metal, and thus prevents annealing of the assembled parts in the solder bath (1, 7, 8, 9, 10, 11, 12). The silver, however, has no appreciable effect, one way or the other, in influencing the resistance to corrosion.

The arsenical coppers are not widely used in this country, although they are favored in England. It is the English opinion, substantiated by experience and some little experimentation, that the arsenical coppers are somewhat more resistant to corrosion than electrolytic copper (13–21 incl.) It would appear, however, that, even if this is true, the difference is nevertheless slight, and probably of but little commercial significance.

Arsenical coppers, however, are used to advantage where the material is to be exposed to relatively high temperatures. The presence of arsenic appears to inhibit scaling to some degree and for certain applications controlled quantities of arsenic are added to the copper. Most arsenical coppers contain moderate quantities of silver and there is some evidence that the silver so present, acting in conjunction with arsenic, is a factor in the reduction of scaling (2, 22, 23, 24).

The phosphor-deoxidized coppers are used for tubing and other applications where flaring, flanging, and spinning operations might be deleteriously affected by the presence of the copper-copper-oxide eutectic dispersion that is characteristic of electrolytic copper. The use of phosphor-deoxidized copper is advantageous when the metal is to be exposed in processing or service to the action of reducing gases at elevated temperatures. In such cases electrolytic copper is liable to embrittlement due to the deoxidization of the eutectic by the reducing gases (25, 26). The phosphor-deoxidized coppers also are preferable to electrolytic copper when welding operations are to be performed.

In recent years an oxygen-free copper has been marketed, which presents the same advantages as already outlined for the phosphor-deoxidized coppers, and in addition, presents the advantage of unimpaired high electrical conductivity.

[1] Numbers in parentheses refer to Bibliography at end of paper.

In standard commercial forms the phosphor-deoxidized and the oxygen-free coppers are in general more expensive than comparable forms of electrolytic copper and their use in preference to the electrolytic copper is, therefore, only warranted where a definite advantage is secured.

Fire-refined copper is seldom used in the United States in the production of the standard commercial wrought-metal forms. In this country fire-refined copper is usually sold in the form of ingots for the purpose of making copper and copper-alloy castings.

CORROSION-RESISTANT PROPERTIES OF COPPER

While there are certain differences as indicated in the common commercial kinds of copper, none of these modifications exerts a profound influence on the characteristics of the metal in respect to its ability to resist corrosion.

TABLE 2 TYPICAL USES OF COPPER IN CHEMICAL EQUIPMENT

Material	Equipment
Phenolic resins..........	Stills, fractionating columns, condensers (51)
Soda pulp...............	Caustic evaporators (51)
Copper nitrate...........	Pumps
Copper sulphate..........	Piping, storage
Potassium hydroxide......	Evaporator tubes
Sodium hydroxide........	Evaporator tubes
Acids	
Acetic................	Stills
Citric................	Filters, piping
Fatty.................	Piping-stills (50, 52)
Gallic................	Piping
Lactic................	Evaporators
Oxalic................	Evaporators
Phthalic (solu.).......	Stills
Salicylic..............	Evaporators, piping
Tannic................	Autoclaves (50)
Alcohols[a]	
Amyl..................	Coils, kettles, pumps, stills, storage
Benzol................	Coils, kettles, pumps, stills, storage
Ethyl.................	Coils, kettles, pumps, stills, storage
Ethylene glycol........	Coils, kettles, pumps, stills, storage
Glycerol..............	Coils, kettles, pumps, stills, storage
Isoamyl...............	Coils, kettles, pumps, stills, storage
Isobutyl..............	Coils, kettles, pumps, stills, storage
Isopropyl.............	Coils, kettles, pumps, stills, storage
Methyl................	Coils, kettles, pumps, stills, storage
Propyl................	Coils, kettles, pumps, stills, storage
Formaldehyde...........	Stills, reactors, storage
Glycerine..............	Condenser tubes (51)

[a] All data other than specifically noted from ref. (52).

In general, it can be stated that copper withstands atmospheric corrosion and sea-water corrosion as satisfactorily as any commercially available metal, and it has been used for centuries in construction where resistance to attack of this nature is necessary. In addition, it can be stated that copper is substantially immune to the chemical attack of a large variety of industrial chemicals (27–39 incl.), although copper ordinarily should not be used in contact with oxidizing acids and most oxidizing agents, or in situations where alternate exposure to oxidizing conditions and acid reagents is anticipated (28, 40–44 incl.). Typical applications of copper to chemical equipment are shown in Table 2.

In the foregoing connections, and of considerable commercial significance, it should be recognized that the presence of relatively small percentages of certain metallic salts in solutions of nonoxidizing acids is likely to introduce rapid corrosive action. Metallic salts readily susceptible of chemical reduction are particularly dangerous in this respect; and ferric, stannic, mercuric, and cupric compounds, particularly, constitute a source of danger when present in an otherwise nonoxidizing acid solution, which of and by itself might be inactive with respect to copper (30, 31, 41, 45, 46, 47).

Ammonia and carbon dioxide are two commonly encountered substances, which in the presence of moisture and in relatively low concentration can constitute active corrosive agents with respect to copper (30, 35, 43, 48).

Copper is used in many forms and in many applications where its high thermal and electrical conductivities are of primary importance. In such situations its resistance to corrosion is a property of value, but commonly of somewhat secondary importance, and corrosion problems are not normally encountered in such fields.

As a material of construction, copper should be regarded as a metal having great resistance to corrosion under a wide range of conditions and rendered attractive to the engineer by its malleability, ductility, and the readiness with which it may be worked, formed, soldered, and brazed, and, under proper conditions, welded. Its physical properties, particularly with respect to tensile strength, are not impressive, and pure copper, where its use is based primarily on its resistance to corrosion, is usually employed only as a covering or lining, rather than as a basic material of construction. An outstanding exception, however, to this general statement is the case of tubes and pipes where adequate strength to meet service conditions is readily obtainable because of the strength inherent in the shape of a tubular article.

Because of its physical and chemical characteristics copper is frequently used as a base for applied coatings. Typical of such products is tinned copper, which finds application in many industries where the presence of bare copper for one or another reason may be objectionable.

A similar product is lead-coated copper which is used primarily in architectural applications for the purpose of obtaining decorative effects, and to some extent in the construction of ventilating ducts when the lead surface is peculiarly desirable with respect to the particular gases being handled and where the physical characteristics of the copper base are adequate to meet the structural requirements.

Before discussing in detail typical design and operating factors which may influence the life of copper parts in service, let us consider the basic physical and chemical properties of the more common types of copper alloys.

BRASSES

The most widely used and the best-known copper-base alloys are the brasses. These are basically binary alloys of copper and zinc, but in many instances certain of their physical and chemical properties are modified or controlled by intentional additions of small amounts of one or more other metallic constituents.

As a rather broad generality, it might be said that brasses are used by the engineer in applications where it is desired to improve upon a basic characteristic of copper, and where such improvement may be effected at a sacrifice only of such other characteristics of copper as are unimportant in respect to the particular application at hand.

Among the brasses we find alloys which are markedly stronger than copper, and in consequence can be used more satisfactorily than the latter in structural applications. Such alloys retain a resistance to corrosion adequate to meet the requirements of many widespread uses. Indeed, with respect to certain specific causes of corrosion, certain of the brasses are more resistant than the parent metal itself (29, 30, 53–58 incl.). This latter is particularly true where so-called "impingement corrosion" or erosion is involved; but it is seldom that a brass is actually more passive than copper itself.

Commonly, certain mill products and certain manufactured products may be produced at less cost if, instead of copper, certain of the brasses are used, and, obviously, therefore, cost frequently is the consideration which leads to the use of brass rather than copper for a given product.

It is true that, where a brass alloy offers an advantage over the parent metal, that advantage is usually had at the sacrifice of both electrical and thermal conductivity, but it is equally true that these two latter properties are commonly of negligible significance in many applications where corrosion resistance is desirable.

Brasses are manufactured commercially in a range of composition running from approximately 95 per cent copper and 5 per cent zinc down to 55 per cent copper and 45 per cent zinc. Within this range of composition as modified by the addition of numerous other constituents, there are literally hundreds of commercial brass alloys of varying composition and properties.

CHARACTERISTICS OF THE IMPORTANT BRASSES

It would be impossible within the scope of this paper to give detailed and specific information with respect to each commercial brass alloy. Table 3 lists the more important commercial brasses and gives their composition and fundamental properties. Figs. 1, 2, and 3 illustrate graphically variations of certain physical characteristics of typical brass alloys capable of being secured by a control of mill operations. Table 4 lists general information with respect to the corrosion resistance of the more important brasses.

The tables given, and the references cited, present detailed information sufficient to answer any usual question that might be asked with reference to the performance of a given brass in contact with a definite corrosive substance. There are, however, in this respect certain general characteristics of this type of alloy that can be usefully discussed.

First, brasses having from nearly 100 per cent down to 64 per cent copper are structurally a single-phase solid solution of zinc and copper. This is termed the "alpha" phase. Below 64 per cent copper, a second or "beta" phase appears, and the commercial alloys ranging from this copper content downward exhibit a mixture of the two phases and are known as the "alpha-beta" brasses. As the copper content decreases, the beta phase predominates and the alloys rapidly become brittle and valueless structurally. In the binary copper-zinc alloys the maximum ductility will be found in the alloys having in the neighborhood of 70 per cent copper, and the maximum strength

will be found in the alloys having from 60 to 63 per cent copper, in which latter case the beta constituent is effective in hardening and strengthening the alloy.

Lead is frequently added to brasses to increase their machinability. In the case of the alpha-beta brasses the presence of lead does not affect, in any material way, the cost of mill processing. In the alpha range, however, lead, even in small amounts, does increase the difficulty and expense of the fabricating operations. Lead is not soluble in the brasses, and has little significant effect on their resistance to corrosion.

Manganese and iron are occasionally used as additions to alpha-beta brasses for hardening and increasing the strength of the product. Although there is some evidence tending to establish that such additions exert an unfavorable influence on

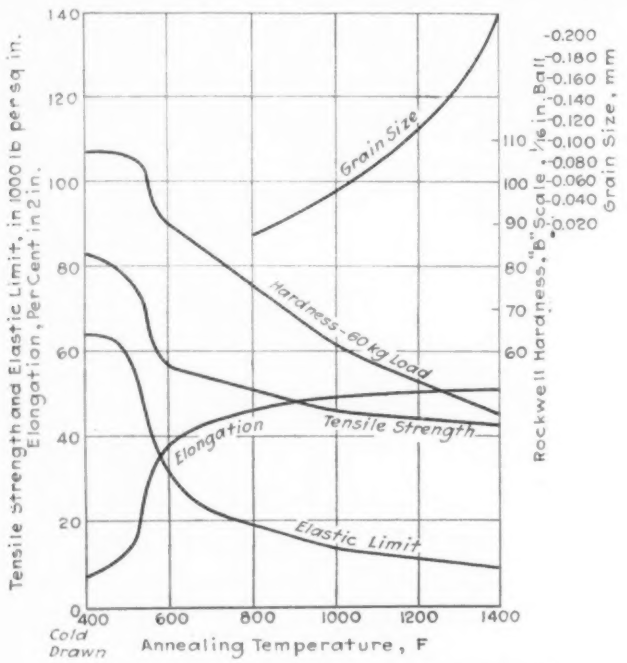

FIG. 1 PHYSICAL PROPERTIES OF 80–20 BRASS SHEET
(Cold-rolled 4 B & S., numbers hard to 0.042 in. and annealed as shown)

the resistance of the alloy to corrosive attack, such influence, if it exists, is relatively minor (33, 34, 35, 53, 54, 59–63 incl.).

Additions of tin and aluminum, on the other hand, although having but minor effects on the physical properties of brasses, exert a pronounced effect in increasing the resistance to certain kinds of corrosion, which will be discussed later.

Many applications of brasses are determined by their ready machinability, the ease with which they can be drawn, spun, or stamped, or by reason of some other mechanical characteristic, in addition to their satisfactory resistance to moderate corrosive action.

RESISTANCE OF BRASSES TO CORROSIVE ACTION

In general, we seldom find brasses successfully used in direct contact with active chemical substances. Their useful field of application, in respect to corrosion resistance, is to products in which resistance to atmospheric corrosion, or the corrosive action of industrial or domestic waters, is desirable or necessary, and to articles and apparatus subject to the action of chemically neutral or basic substances relatively mild in corrosive action (55, 91).

Brasses for the most part are adversely affected by the same substances which have an adverse effect on copper, and in numerous instances are corroded by substances, particularly those which might be termed active chemical reagents, which do not affect copper to any appreciable extent. A noteworthy exception to this generality is that in resisting the corrosive attack of sulphides the brasses, on the whole, are better than copper, and their superiority in that respect becomes more marked as the zinc content increases (64, 117). Further, it is of

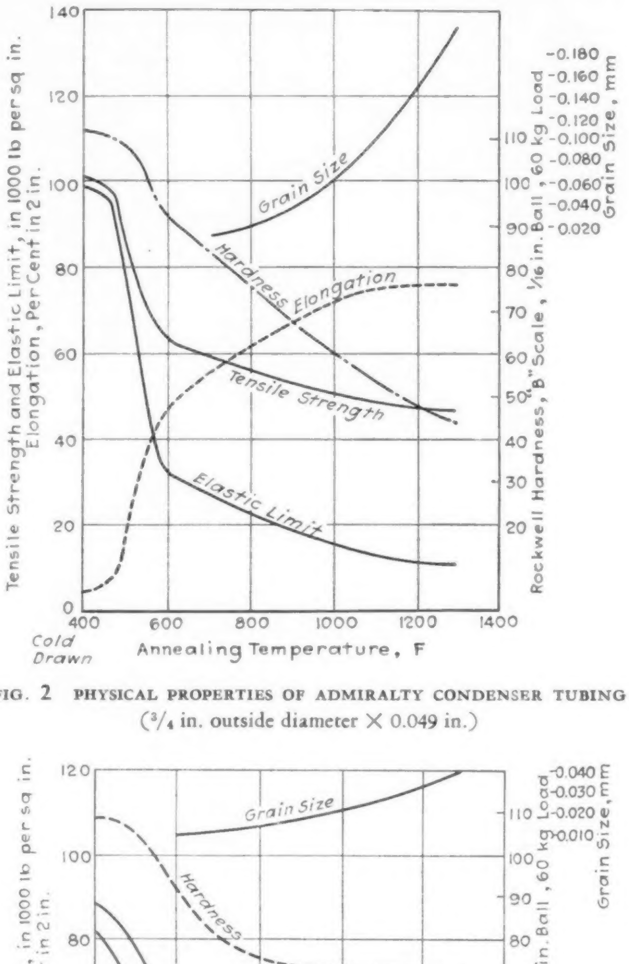

FIG. 2 PHYSICAL PROPERTIES OF ADMIRALTY CONDENSER TUBING
($^3/_4$ in. outside diameter × 0.049 in.)

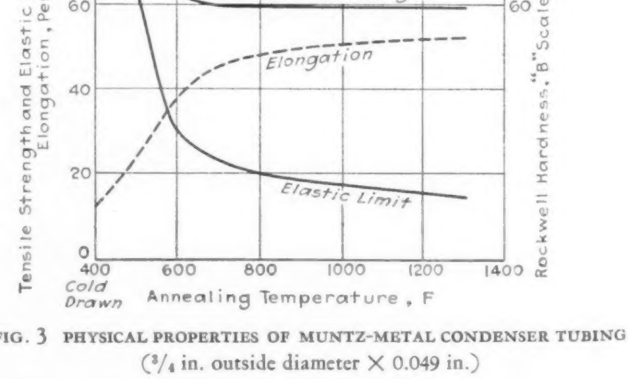

FIG. 3 PHYSICAL PROPERTIES OF MUNTZ-METAL CONDENSER TUBING
($^3/_4$ in. outside diameter × 0.049 in.)

particular interest, that in combating the corrosion of sea water, especially when such corrosive attack is aggravated by the action of atmospheric oxygen or complicated by conditions which introduce impingement attack or erosion, certain of the modified brasses, for example, aluminum brass, Admiralty

TABLE 3 PHYSICAL PROPERTIES OF THE BRASSES

Material	Tensile strength, lb per sq in. Hard	Tensile strength, lb per sq in. Soft	Elastic limit, lb per sq in. Hard	Elastic limit, lb per sq in. Soft	Elongation, per cent Hard	Elongation, per cent Soft	Rockwell B hardness Hard	Rockwell B hardness Soft	Melting point, C	Density, lb per cu in.	Coefficient of expansion	Electrical conductivity[1]	Thermal conductivity[2]	Modulus of elasticity, lb per sq in.
Red brass (85 Cu, 15 Zn)	89,000	45,000	85,000	15,000	4.5	43	89	3	1020	0.316	0.0000187	37.0	0.38	15×10^6
70–30 Brass (70 Cu, 30 Zn)	95,000	53,000	91,000	16,000	7	51	93	15	955	0.308	0.0000199	27.58	0.290	15×10^6
High brass (65 Cu, 35 Zn)	93,000	51,000	73,700	18,500	2	50	90	30	930	0.306	0.0000202	26.8	0.285	15×10^6
Admiralty (71 Cu, 28 Zn, 1 Sn)	100,000	53,000	98,000	18,000	4	67	95	15	935	0.308	0.0000202	24.65	0.263	15×10^6
Aluminum brass 76 Cu, 22 Zn, 2 Al)	83,000	62.000	75,000	16,000	5	52	86	33	970	0.301	0.0000185	22.56	0.240	15×10^6
Muntz metal (60 Cu, 40 Zn)	88,000	59,000	82,000	15,000	5	52	91	24	905	0.304	0.0000208	28.60	0.300	15×10^6
Commercial bronze (90 Cu, 10 Zn)	67,000	37,600	55,000	15,000	3	40	75	1	1045	0.318	0.0000182	40.90	0.446	15×10^6
Roman or Tobin bronze (60 Cu, 39.25 Zn, 0.75 Sn)	90,000	54,000	70,000	15,000	4	40	93	55	885	0.304	0.0000211	24.93	0.279	15×10^6

Data based on information published by the Revere Copper and Brass, Inc., American Brass Company, and Chase Brass and Copper Company.
[1] Per cent of International Annealed Copper Standard.
[2] Cal. per sq cm per cm per sec per C at 20 C.

TABLE 4 CORROSION DATA—BRASSES—RATES EXPRESSED AS PENETRATION IN INCHES PER YEAR, REF. (79)

Test no.	1	2	3	4	5	6	7	10	10A	11	12	13	14	15
Red brass (85 Cu, 15 Zn)	0.0005	0.0015	0.0019	nil	0.0025	0.0087	0.0852	0.0343	0.0065	....	0.0001	0.0153	0.0027	....
Two-and-one brass (67 Cu, 33 Zn)	nil	0.0019	0.0029	0.0002	0.0018	0.0068	0.0005	0.0293	0.0069	....	....	....	....	0.0296
Tobin or Roman bronze (60 Cu, 39 Zn, 1 Sn)	nil	0.0028	0.0030	0.0001	0.0022	0.0034	0.0002	....	....	....	....	....	....	....
Naval brass (cold roll) (63 Cu, 35 Zn, 2 Sn)	nil	0.0039	0.0026	0.0002	0.0029	0.0014	0.0004	0.0539	0.0045	....	....	....	....	....
Naval brass (hot roll) (63 Cu, 35 Zn, 2 Sn)	nil	0.0030	0.0038	0.0001	0.0018	0.0021	0.0003	....	....	....	....	....	....	....
Muntz metal (cold roll) (60 Cu, 40 Zn)	nil	0.0039	0.0027	0.0001	0.0023	0.0035	0.0003	0.1579	0.0068	....	....	....	0.0024	....
Muntz metal (hot roll) (60 Cu, 40 Zn)	0.0001	0.0047	0.0025	0.0001	0.0033	0.0028	0.0004	....	....	....	....	....	....	....
Admiralty (cold roll) (70 Cu, 29 Zn, 1 Sn)	nil	0.0016	0.0017	nil	0.0044	0.0030	0.0008	....	....	....	....	0.0092	0.0027	0.0316
Admiralty (hot roll) (70 Cu, 29 Zn, 1 Sn)	nil	0.0027	0.0023	0.0001	0.0028	0.0083	0.0012	0.0349	0.0058	....	0.0001	0.0084	0.0038	....
Manganese bronze (cold roll) (56 Cu, 41 Zn, 1 Al, 1 Fe, 0.5 Sn, 0.5 Mn)	nil	0.0022	0.0028	0.0002	0.0015	0.0025	0.0004	....	....	....	....	....	....	....
Manganese bronze (hot roll) (56 Cu, 41 Zn, 1 Al, 1 Fe, 0.5 Sn, 0.5 Mn)	nil	0.0026	0.0034	0.0002	0.0022	0.0018	0.0003	....	....	....	....	....	....	....
Manganese bronze (cast) (58 Cu, 38 Zn, 1 Sn, 1 Fe, 1 Pb)	nil	0.0027	0.0034	0.0001	0.0027	0.0029	0.0003	....	....	....	....	....	....	....
Copper	0.0025	0.0029	0.0012	nil	0.0244	0.0506	100%	0.0515	0.0069	0.0001	0.0002	0.0088	....	0.0208

Corrosion rates are average. For test conditions see Table 10.

metal, and possibly 85/15 brass (known as "red brass"), give materially better service in respect to withstanding corrosion than copper itself (65, 66, 67).

Brasses containing less than 85 per cent copper when exposed to acidic media frequently fail in a characteristic manner termed "dezincification." Failures of this kind are identified by the appearance of spongy areas of copper in the form of either layers or so-called "plugs" on the affected surface. This spongy copper is a consequence of the solution of fractions of the alloy in the media and a redeposition of the copper by chemical displacement. Generally speaking, dezincification is confined to the brasses of higher zinc content, while those of higher copper content, such as 85/15 brass, commonly give satisfactory service in applications where the former are prone to failure through dezincification (55, 68–76 incl.).

Admiralty metal, in which 1 per cent of tin is substituted for an equal amount of zinc in 70/30 brass, appears to be effective in respect to a reduced tendency toward dezincification; and this alloy has found widespread application, particularly to condenser tubes (55). To a certain extent this same effect of tin in reducing the tendency toward dezincification is noted in the alpha-beta range of brasses, and the alloy of 60 per cent copper, 1 per cent tin, and 39 per cent zinc, which is of this type, has been used in the manufacture of marine shafting for many years. Naval brass is a generic term for this last-mentioned alloy. When prepared from materials of especially high purity and fabricated by methods which increase resistance to corrosion fatigue, the alloy is ordinarily offered under various trade names, such as Tobin bronze, Roman bronze, etc.

Arsenic in small fractional percentages is demonstrably ef-

fective in repressing or inhibiting dezincification in the brasses of higher zinc content. It is becoming rapidly recognized that good metallurgical practice calls for the presence of small fracti al percentages of arsenic in brass condenser tubes (55, 77, 78).

One of the principal industrial applications of the brasses is to pipes and tubes to serve in condensers, heat exchangers, evaporators, and similar types of equipment and to serve as conduit for industrial waters, sea water, and industrial wastes.

In such uses active chemical attack is seldom to be anticipated. The engineer in attempting to determine which metal or alloy will show the longest life and the maximum economic advantage must give careful consideration to his operating conditions and their probable influence on the various materials of construction being considered. Such factors as operating temperatures, the presence, or absence, of entrained air, and circulating velocities, all vary from one installation to another and profoundly influence the performance of a given tube in contact with a given fluid.

In this connection it is important that the designing engineer recognize that there are many varieties of brasses, each possessing distinctive characteristics, and that in a given installation under specific conditions of operation it is entirely possible that while one kind of brass might give absolutely satisfactory service another kind might fail rapidly and completely. Further, it should be recognized that there are many copper-base alloys, other than brasses, particularly designed to meet severe corrosive conditions, and that the engineer's range of choice is, therefore, by no means restricted to the copper alloys containing zinc. These other copper-base alloys, principally the copper-silicon alloys, the tin bronzes, the aluminum bronzes, cupronickels, and nickel silvers, will now be discussed.

COPPER-SILICON ALLOYS

While copper is in general use in the chemical and processing industries as a material for tank construction, sheathing, and similar applications, the brasses, in spite of their improved structural characteristics as compared to copper, are not commonly used for these purposes. The reason for this is that the improved physical properties of the brasses ordinarily are secured at a partial sacrifice of the resistance to corrosion that is a characteristic of copper.

Within recent years the copper-silicon alloys have been commercially developed and offer a material of high strength as well as excellent resistance to corrosion. These alloys in general possess a resistance to corrosion which is the equivalent of and is similar to that of copper. Indeed, in some instances and applications their corrosion resistance exceeds that of copper (28, 54, 61, 62).

In general, the copper-silicon alloys combine with the corrosion-resisting properties of copper physical properties and structural qualities quite comparable to those of mild steel. Inasmuch as they combine excellent structural properties and corrosion resistance in one alloy, they are of considerable importance to the engineer dealing with corrosion-resisting equipment (80, 81, 82).

It seems unnecessary in this paper to tabulate separately corrosion data for the copper-silicon alloys. From the standpoint of practical engineering it is safe to assume, from a corrosion point of view, that where copper would be satisfactory the copper-silicon alloys would be equally satisfactory, and that where copper would be unsatisfactory there is little probability that the copper-silicon alloys would be otherwise.

Those particular aspects of design, construction, and operation which in respect to corrosion influence the performance of copper in service will in like manner influence the performance of the copper-silicon alloys. While, therefore, from the point of view of corrosion it would appear unnecessary to consider the copper-silicon alloys in separate detail, it is of definite importance to consider the characteristic physical and mechanical qualities of these materials in so far as they affect their application to the construction of corrosion-resisting equipment.

Table 8 and Fig. 4 present data on the physical properties of a

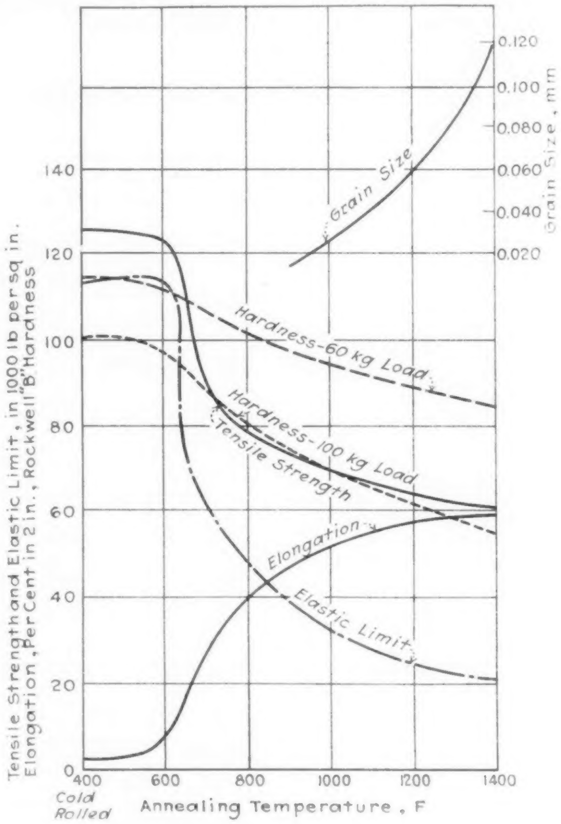

FIG. 4 PHYSICAL PROPERTIES OF COPPER-SILICON ALLOY SHEET
(Type A, cold-rolled 67 per cent, annealed as indicated.)

TABLE 5 PHYSICAL PROPERTIES OF THE SILICON BRONZES

Material	Tensile strength, lb per sq in. Hard	Tensile strength, lb per sq in. Soft	Elastic limit, lb per sq in. Hard	Elastic limit, lb per sq in. Soft	Elongation, per cent Hard	Elongation, per cent Soft	Rockwell B hardness Hard	Rockwell B hardness Soft	Melting point, C	Density, lb per cu in.	Coefficient of expansion	Electrical conductivity[1]	Thermal conductivity[2]
Silicon bronze, type A..........	120,000	67,000	103,000	24,000	10	60	99	65	1000	0.308	0.000017	8.07	0.086
Silicon bronze, type B..........	90,000	42,000	80,000	12,000	10	60	84	20	1030	0.313	0.000017	11.0	0.116

Data based on information published by Revere Copper and Brass, Inc., American Brass Company, and Chase Brass and Copper Company.
[1] Per cent of International annealed copper standard.
[2] Cal. per sq cm per cm per sec per C at 20 C.

typical copper-silicon alloy. This table does not refer to the product of any particular manufacturer, but is intended to be representative of this entire class of product. While the corrosion-resisting properties of copper have been retained in the copper-silicon alloys and excellent physical properties introduced, it will be noted from an inspection of this table that the high thermal and electrical conductivities characteristic of copper have been drastically reduced and are, together with the strength of the alloy, comparable to mild steel. The reduction of the thermal conductivity is of considerable significance in connection with these alloys, as it is a large factor in rendering them easily welded, either with the gas torch, the electric arc, or by resistance methods. Welded joints so obtained are substantially autogenous in character and introduce none of the corrosion problems which are so frequently incidental to the use of soldered or brazed joints.

There are many industrial applications in which welded copper-silicon alloy constructions are superseding, with substantial economy, steel constructions lined or covered with copper or other corrosion-resistant material. The economy inherent in this new type of construction may not always be apparent from a comparison of first costs, but is readily discerned when the maintenance costs of lined equipment are taken into consideration.

There are many other fields of application in which the use of copper-silicon alloys in the form of structural members such as bolts, screws, tie rods, etc., will reduce maintenance and replacement costs to an extent which will more than justify an initial higher material cost. In the past, the use of brasses in such applications has often proved unsatisfactory because of inadequate strength and inadequate resistance to corrosion.

The references to these alloys in the literature are relatively few because of their comparatively recent commercial development. However, the fabricating companies manufacturing these alloys have individually compiled and published information with reference to the properties of their particular products and the methods of welding and otherwise fabricating them. Such information is readily available to the engineer.

TIN BRONZES AND ALUMINUM BRONZES

The tin bronzes, or, as they are commonly called, the phosphor bronzes because of the practice of using phosphorus as a deoxidant in connection with their manufacture, are of some engineering interest. They possess excellent corrosion-resisting properties, which in general are comparable to those of copper and the copper-silicon alloys. However, because of the relatively high cost of the tin entering into their composition and the expensive nature of the fabricating operations necessary to the production of mill products made of them, they are not used extensively in the wrought form as materials of construction.

The excellent mechanical properties obtainable with the tin bronzes are shown in Table 6.

One of the principal applications of the wrought tin bronzes in the construction of corrosion-resisting equipment is for use as welding rod for the purpose of electrically welding copper sheet. The welds so obtained, while not autogenous in character, nevertheless are very satisfactory with respect to strength and appear adequate in most applications in so far as corrosion resistance is concerned. Tin bronzes also are commonly used in the fabrication of such parts as valve seats, springs, and similar small parts, where good corrosion resistance is desirable (35, 48, 67, 80, 81, 83–88 incl.). The high cost of these alloys, however, prevents their widespread application in sheet and other structural forms.

Aluminum bronzes, also, are used to some extent in wrought form, and they also possess high strength and other excellent physical properties. Ordinarily, the amount of aluminum in the commercial wrought forms does not exceed 10 per cent. Table 6 shows the characteristic physical properties of this class of alloy.

In general, the aluminum bronzes, from the standpoint of corrosion, are characterized by excellent resistance to the corrosive attack of acid solutions, and in this respect not only are generally superior to the brasses but, under some conditions, superior to copper and the copper-silicon alloys (28, 89, 90). Under certain conditions, however, it would appear that aluminum bronzes having amounts of aluminum in excess of about 7 or 8 per cent are subject to a type of corrosion analogous to dezincification as mentioned in connection with copper-zinc alloys. Here also there would appear to occur a primary solution of the alloy followed by deposition of spongy copper by displacement (91).

The aluminum bronzes in the wrought form are ordinarily supplied as tubes and rods and seldom as sheets. Their properties in these forms frequently are modified by the addition of small percentages of nickel (81).

In general, the application of wrought aluminum bronzes in the construction of corrosion-resisting equipment is limited by two factors. The first is that wrought forms of these alloys present manufacturing difficulties which tend to increase their cost, and the second is that improper control of the manufacturing operations may introduce causes of failure of the product under exposure to corrosive conditions. These fac-

TABLE 6 PHYSICAL PROPERTIES OF THE BRONZES

Material	Tensile strength, lb per sq in. Hard	Tensile strength, lb per sq in. Soft	Elastic limit, lb per sq in. Hard	Elastic limit, lb per sq in. Soft	Elongation, per cent Hard	Elongation, per cent Soft	Rockwell B hardness Hard	Rockwell B hardness Soft	Melting point, C	Density, lb per cu in.	Coefficient of expansion	Electrical conductivity[1]	Thermal conductivity[2]	Modulus of elasticity lb per sq in.
5 Per cent phosphor bronze............ (95 Cu, 5 Sn, 0.05 P)	105,000	51,000	85,000	15,000	7	55	91	30	1050	0.320	0.0000178	18	0.20	15×10^6
8 Per cent phosphor bronze............ (92 Cu, 8 Sn, 0.05 P)	110,000	55,000	90,000	15,000	3	60	99	38	1030	0.319	0.0000182	13.61	0.154	14×10^6
10 Per cent phosphor bronze............ (89.5 Cu, 10.5 Sn)	115,000	60,000	95,000	16,000	5	65	100	52	1000	0.317	0.0000183	10.6	0.121	15×10^6
Aluminum bronze.... (92 Cu, 8 Al)	134,000	76,000	110,000	30,000	13	55	99	69	1060	0.293	0.0000165	15.23	0.173	15×10^6

Data based on information published by Revere Copper and Brass, Inc. American Brass Company, and Chase Brass and Copper Company.
[1] Per cent of International Annealed Copper Standard.
[2] Cal. per sq cm per cm per sec per C at 20 C.

tors particularly render wide sheet metal of this alloy very expensive and generally unavailable as a commercial product. Still further, the aluminum bronzes are handicapped in respect to their industrial applications by the difficulties they offer to successful welding.

From the point of view of corrosion resistance, the field of application of the wrought aluminum bronzes of the most interest at present appears to be the condenser-tube field, in which they have been recently used with some indications of success. However, experience with them for such use is not yet sufficiently extensive to warrant the drawing of definite conclusions as to their actual value in that type of application.

CUPRONICKELS AND NICKEL SILVERS

The alloys of copper and nickel, commonly termed "cupronickels," have found extensive application in the engineering fields in the form of condenser and heat-exchanger tubes. The trend toward the adoption of cupronickel in such applications has been increasingly marked as the design and operation of land and marine power stations has introduced factors leading to an increasingly severe corrosive action on the condenser tubes.

The most common of these tube alloys are those containing 80 per cent copper and 20 per cent nickel, and 70 per cent copper and 30 per cent nickel. Each of these has excellent physical and chemical properties. In this connection the reader is referred to Table 7 which lists the general physical characteristics of the standard cupronickel condenser-tube alloys, including those containing zinc.

There has been a considerable use of cupronickel tubes which have been modified as to properties by the inclusion in the alloy of zinc in amounts up to 5 and 6 per cent. While the imparting of a beneficial effect in respect to resistance to corrosion by the inclusion of zinc is somewhat open to question, there is no persuasive evidence that any notably deleterious effect is caused by so modifying the alloy.

Characteristically, the cupronickels are notably resistant to general chemical attack, impingement attack, and erosion. Where operating conditions are particularly severe, the desirable characteristics of the 70/30 cupronickel condenser tubes are leading to its extensive use.

While it is true that the aluminum brasses, in respect to their ability to withstand impingement corrosion, closely approximate cupronickel and are less costly, cupronickel nevertheless offers outstanding advantages when compared with aluminum brasses as more severe operating conditions are encountered. When impingement corrosion or erosion alone are to be considered, aluminum brass might constitute a sound economic engineering choice, but where chemical action is accelerated by operating temperatures in excess of 100 F, the aluminum brasses can, and on occasion do, fail rapidly.

For these reasons the cupronickels are being increasingly applied in the form of heat-exchanger tubes in the oil and other processing industries, in cases where operating and tube-wall temperatures are sufficiently high to cause rapid deterioration of Admiralty, aluminum brass, and similar modified brass tubes.

Cupronickel in the form of sheet and strip has not as yet been extensively applied in the construction of industrial equipment. However, the use of cupronickels in condenser tubes, and the uniformly excellent results obtained with them, has called attention to their excellent properties as corrosion-resisting metals, and, therefore, it is only reasonable to expect that the use of these alloys in sheet and other structural forms will increase (14, 20, 21, 81, 92–96 incl.).

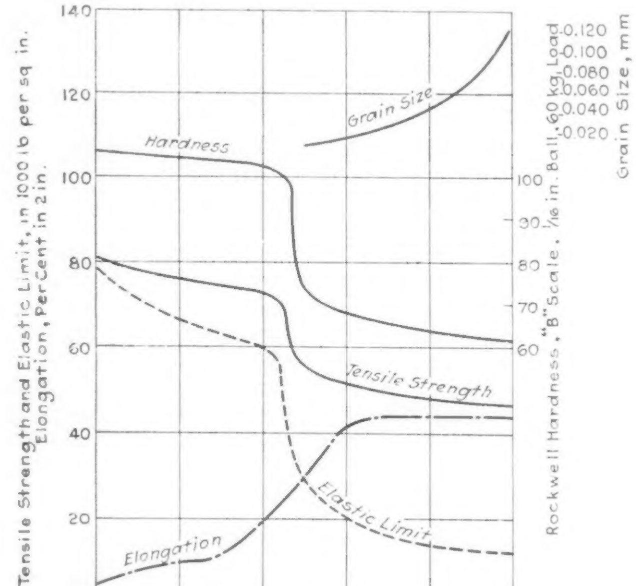

FIG. 5 PHYSICAL PROPERTIES OF 20 PER CENT NICKEL-SILVER CONDENSER TUBING

($^3/_4$ in. outside diameter × 0.049 in.)

TABLE 7 PHYSICAL PROPERTIES OF THE COPPER-NICKEL ALLOYS

Material	Tensile strength, lb per sq in.		Elastic Limit, lb per sq in.		Elongation, per cent		Rockwell B hardness		Melting point, C	Density, lb per cu in.	Coefficient of expansion	Electrical conductivity[1]	Thermal conductivity[2]	Modulus of elasticity, lb per sq in.
	Hard	Soft	Hard	Soft	Hard	Soft	Hard	Soft						
Cupronickel (80 Cu, 20 Ni)	80,000	49,000	75,000	18,000	3	42	87	21	1200	0.321	0.0000159	6.47	0.087	17.0
Cupronickel (70 Cu, 30 Ni)	84,000	49,000	80,000	18,000	4	50	87	20	1220	0.323	0.0000162	4.75	0.093	17.0
20 Per cent nickel silver (70 Cu, 10 Zn, 20 Ni)	81,000	49,500	78,000	16,500	5	44	86	12	1150	0.321	0.0000164	4.8	0.069	18.0
18 Per cent nickel silver (64 Cu, 18 Ni, 18 Zn)	100,000	54,500	80,000	18,000	5.5	42	94.5	40	1110	0.316	.....	5.91	0.080	18.0
10 Per cent nickel silver (65 Cu, 25 Zn, 10 Ni)	90,000	50,000	75,000	18,000	3	45	90	52	1010	0.313	.....	8.27	0.110	17.5

Data based on information published by Revere Copper and Brass, Inc., American Brass Company, and Chase Brass and Copper Company.

[1] Per cent of International Annealed Copper Standard.

[2] Cal. per sq cm per cm per sec per C at 20 C.

The so-called nickel silvers can be considered as brasses in which varying percentages of the copper content have been replaced by nickel. The nickel silvers in general possess excellent ductility and strength, and are well adapted to stamping and forming operations. They resist tarnish and corrosion better than the brasses, and for this reason and because of their white color, are widely used as a base for plated table ware, and in hollow ware, key stock, extruded architectural shapes, and similar applications (97–103 incl.).

There is some application of sheet and strip nickel silver in the food-processing industries, but these alloys in wrought form are not commonly used in the construction of industrial equipment.

Table 7 lists the general physical properties of the more common commercial nickel-silver alloys, and Fig. 5 graphically illustrates how in 20 per cent nickel silver these properties may be modified or controlled by annealing.

CASTING ALLOYS

So far this discussion has been confined, in respect to alloys, almost exclusively to those which are susceptible of mill production in wrought form, such as sheet, strip, tube, rod, wire, and shapes. While most of these alloys are of particular interest in the wrought form, many of them nevertheless can also be used in the form of castings. Many of the popular casting alloys, on the other hand, cannot be commercially fabricated into wrought forms by either hot- or cold-working.

The engineer in selecting an alloy for a corrosion-resistant casting obviously must, as his primary concern, consider the corrosion resistance of available casting alloys, and then give his attention to the mechanical and economic factors involved, such as the strength of the alloys in the cast form, their machinability, cost, etc. The range of alloy composition, however, is not limited in the case of a casting by the necessity of insuring that the composition be such as will permit mill fabrication of the alloy selected.

Brass castings are extensively used for valve bodies, pipe fittings, and similar products where only the normal corrosive attack of industrial and domestic waters and similar substances are anticipated. In this type of application we find an alloy commonly known as "85-5-5-5," widely used and giving satisfactory results in its usual applications. However, when corrosion problems become more severe than those just mentioned, or higher strengths are required, as is illustrated by the application of castings to pickle-tub racks and similar articles, there is an extensive use of the aluminum bronzes. With cast aluminum bronze, high strengths and high resistances to direct chemical attack are secured, and these properties generally are superior to those offered by copper, or the silicon-copper alloys, or the common brasses.

In many applications, particularly in the dairy and other food-processing industries, and in ornamental architectural uses as well, there is a wide use of cast nickel-silver alloys.

In general, it may safely be said that there is a wide permissible range of composition in the copper-base casting alloys. Necessity, and, it would seem, even personal whims, govern the composition of many copper-base alloys used in practice, and it would serve no useful purpose to attempt in this paper to enumerate all of the many variations which are to be encountered, or their physical and chemical properties. Table 8 gives the composition of certain widely used copper-base alloys and the rates at which they are attacked by certain reagents commonly encountered in the oil industry. Table 9 lists the physical properties of the more important of these alloys (35, 61, 104, 105).

As a further generality, it may be stated that the chemical characteristics of the copper-base casting alloys are qualitatively similar to those of the corresponding wrought alloys previously discussed. Because of a wider latitude in composition, the cast alloys may present quantitative variations

TABLE 9 PHYSICAL PROPERTIES OF TYPICAL CAST BRONZES

Composition	Tensile strength, lb per sq in.	Elastic limit, lb per sq in.	Elongation, per cent	Red. area, per cent
Aluminum bronze				
(Cu, Al 0.9, Fe 1.25)	75,000	20,000	30	35
(Cu 88, Al 10, Fe 2)	75,000	30,000	18	18
Gun metal				
(Cu 88, Sn 10, Zn 2)	30,000–45,000	11,000–14,000	15–40	..
(Cu 88, Sn 8, Zn 4)				
Eighty-five three fives (Cu 85, Sn 5, Zn 5, Pb 5)	30,000	10,000	15	..

TABLE 8 CORROSION DATA—CAST AND WROUGHT BRONZES—RATES EXPRESSED AS PENETRATION IN INCHES PER YEAR, REF. (79)

Test No.	1	2	3	4	5	6	7	10	10A	11	12	13	14	15
Cast bronze (80 Cu, 8 Zn, 4 Sn, 8 Pb)	0.0006	0.0026	0.0017	0.0001	0.0037	0.0113	0.0586	....	....	0.0003	....	0.0138	....	....
Cast bronze (acid metal) (85.5 Cu, 10.5 Sn, 4 Pb)	0.0006	0.0040	0.0017	nil	0.0127	0.0112	100%	0.0463	0.0109	....	....	....	....	....
Valve metal (86 Cu, 4 Zn, 7 Sn, 3 Pb)	0.0013	0.0028	0.0017	nil	0.0090	0.0347	0.1059	....	....	....	....	....	0.0037	....
Bronze (88 Cu, 12 Sn)	0.0006	0.0024	0.0023	nil	....	0.0024	0.0941	0.0397	0.0129	0.0001	0.0001	0.0065	0.0036	....
Cast bronze (88 Cu, 10 Sn, 2 Pb)	0.0018	0.0021	0.0025	nil	0.0167	0.0214	100%	....	....	0.0011	0.0008	0.0135	....	0.004
Bronze (88 Cu, 2 Zn, 10 Sn)	0.0003	0.0003	0.0016	nil	0.0056	0.0033	0.0703	....	....	0.0005	0.0002	0.0095	....	0.0078
Bronze (77 Cu, 8 Sn, 15 Pb)	nil	0.0037	0.0028	0.0002	0.0084	0.0193	100%	0.1435	0.0098	0.0006	0.0005	0.0157	0.0024	....
Aluminum bronze (90 Cu, 10 Al)	....	....	0.0012	....	0.0031	0.0189	0.0585	....	....	....	....	....	....	....
Aluminum bronze (cold-rolled) (88–96 Cu, 2–10 Al, (FE)	0.0004	0.0015	0.0015	nil	0.0100	0.0320	0.0883	0.0586	0.0057	....	....	....	0.0033	....
Aluminum bronze (hot roll) (94 Cu, 6 Al)	0.0013	0.0020	0.0013	nil	0.0078	0.0298	0.0919	....	....	0.0001	0.0001	0.0067	....	....
Aluminum bronze (89 Cu, 10 Al, 1 Fe)	0.0002	....	0.0011	nil	0.0183	0.0096	0.0376	....	....	....	....	....	....	....

For test conditions see Table 10

TABLE 10 CORROSIVE CONDITIONS FOR TABLES 4 AND 8, REF. (79)

Test no.	Service	Temperature or pressure	Period of tests	Remarks
1	Fresh water	100–120 F	186 days	Open condenser, no O_2
2	Salt water	100–120 F	164 days	Open condenser, no O_2; pH 8.5, NaCl 4–4.5 g per liter
3	Salt water	100–120 F	149 days	
4	Steam	150 lb per sq in.	206 days	Steam trap, vapor
5	Crude-oil vapor	Atm temp	195 and 175 days	Light West-Texas crude, agents—O_2, H_2O, H_2S
6	Naphtha	Atm temp	125 days	Agents—H_2S, H_2O, HCl
7	Naphtha-vapor cracking-coil bubble tower	350 F, 90 lb per sq in.	136 days	Agents—H_2S, mercaptans, naphthenic acids
10	HCl, 5 per cent	Room temp	24 hr	HCl for cleaning
10A	HCl, 5 per cent with acid sludge 3 per cent	Room temp	24 hr	HCl for cleaning and sludge for inhibitor
11	Caustic soda (lab. tests without agitation)	Room temp	50 days	NaOH 468 gr per liter Na_2S 17.6 gr per liter
12	Caustic soda (lab. tests without agitation)	Room temp	60 days	NaOH 155 gr per liter Na_2S 28 gr per liter
13	Acid wash water	Atm temp	75 days	Agents—SO_2, NaCl, SO_3
14	Separated water from crude naphtha	....	64 days	H_2O pH 4.0; HCl, H_2S
15	Rerun naphtha	100 F	21 days	pH about 3, small amounts H_2S and SO_2

TABLE 11 TYPICAL USES OF CAST BRASS AND BRONZES IN CHEMICAL EQUIPMENT

Agent	Parts	Class of alloy
	BRONZES	
Hydrochloric acid (dilute)	Pumps and air lifts	Aluminum bronzes, phosphor bronzes
Sulphuric acid (6 per cent).............	Pickling-tank equipment	Aluminum bronzes
Dilute (below 75 per cent)	Pumps	Aluminum bronzes
Cold and hot below 50 per cent	Storage	Silicon bronzes
Sulphurous acid	Pumps	Aluminum bronzes
Alums	Pumps	Leaded bronze
Aluminum sulphate	Pumps	Leaded bronze
Copper nitrate	Pumps	Bronze
Copper sulphate	Pumps	Aluminum bronze
Ferrous sulphate	Filters	Bronze
Potassium chloride	Pumps	Bronze, aluminum bronze
Sodium chloride	Piping and pumps	Naval brass
Sodium sulphate	Pumps	Bronze
Zinc chloride	Evaporators	Silicon bronze
Zinc nitrate	Pumps	60–38–2 Cu, Zn, Sn bronze
		Bronze, aluminum bronze
Zinc sulphate	Pumps	Bronze, aluminum bronze
Potassium hydroxide	Storage	Aluminum bronze
Oxygen	Valves	Bronze
Sulphur dioxide	Fans	Bronze, aluminum bronze
Sulphur dioxide (moist gas) below 300 F	Piping	Aluminum bronze
Sulphite liquor	Pumps, valves	Bronze
Acetic acid	Filters	Bronze
Acetic acid	Piping	Aluminum bronze
Acetic acid (glacial)	Piping	Aluminum bronze
Acetic acid (glacial)	Pumps	Aluminum bronze
Fatty acids	Condensers, pumps	Aluminum bronze
Gallic acid	Pumps	Bronze
Lactic acid	Pumps	Bronze
Salicylic acid	Pumps	Bronze
Alcohols	Pumps	Bronze
	BRASSES	
Alums	Piping	Brass
Sodium chloride	Condenser tubes	Admiralty brass
Sludge acid (dilute)	Pipe	Brass
Fatty acids (dilute)	Pumps	Brass
Glycerine (51)	Condenser tubes	Admiralty

Reference (52) unless otherwise noted

from the properties of the wrought alloys, but the corrosion data previously submitted will, it is believed, serve as an adequate guide in respect to corrosion resistance in any consideration of copper-alloy castings.

Table 11 lists some typical uses of cast brass and bronzes in chemical equipment.

DESIGN AND MECHANICAL FACTORS

It is, of course, obvious that the designing engineer should have a full comprehension of the physical and mechanical characteristics of his materials of construction as well as a knowledge of their chemical properties when designing corrosion-resisting structures and equipment.

In this connection it is often overlooked that cuprous materials do not have a "yield point" in the sense in which that phrase is used in connection with ferrous materials, and that, therefore, where yield strengths, or yield points, are given for cuprous materials, such values are really only expressions of a property that by custom is assumed to exist, but which in fact has no real existence. The value of the assumed property of the yield point of a cuprous material is only an approximation of the value of its elastic limit. It is, therefore, recommended that the designer in working with copper alloys, base his design on the existent property of elastic limit.

The value of the elastic limit of a cuprous material may be determined by the method illustrated in Fig. 6. Briefly, that method consists in plotting from the stress-strain curve equal increments of stress against corresponding increments of strain. The point at which the graph so obtained shows a marked change in slope is for all practical purposes the elastic limit of the material. The soundness of this method is indicated by Fig. 6 in which is included load-unload curves showing that specimens of material loaded to below, and up to, the value of the elastic limit so determined, have no permanent set when the load is released, while specimens loaded in excess of that value have a permanent set upon release of the load. It is felt that values of elastic limit so determined have a real significance for purposes of mechanical design and that the use of such values is to be preferred to the use of the more or less fictitious yield strengths arrived at by arbitrary definition (106–109 incl.).

In addition to considering the basic physical and chemical properties of a corrosion-resisting material, the engineer must take cognizance of the characteristics of that material when in the particular structural form in which it is to be used. An alloy bar, for example, or a tube or sheet possess certain characteristics which are imparted to it by the fabricating operations to which it has been subjected and which in many instances exercise a profound influence on its ability to stand up satisfactorily under corrosive attack.

Copper-base alloys are seldom susceptible of hardening and strengthening through heat-treatment, and in most industrial forms these alloys are tempered by cold-working. In certain of these alloys, notably the brasses, the aluminum bronzes, and the silicon-copper alloys, excessive stresses, residual in the metal as a result of cold-working, are likely to lead, under the influence of even mild corrosive attack, to stress-corrosion cracking, with resulting rapid failure of the part in question. Structural forms of these alloys, to insure against such failure, should be relieved of residual stresses by so-called "relief annealing," that is to say, heat-treatment below the recrystallization (or softening) temperature, whenever such treatment is possible.

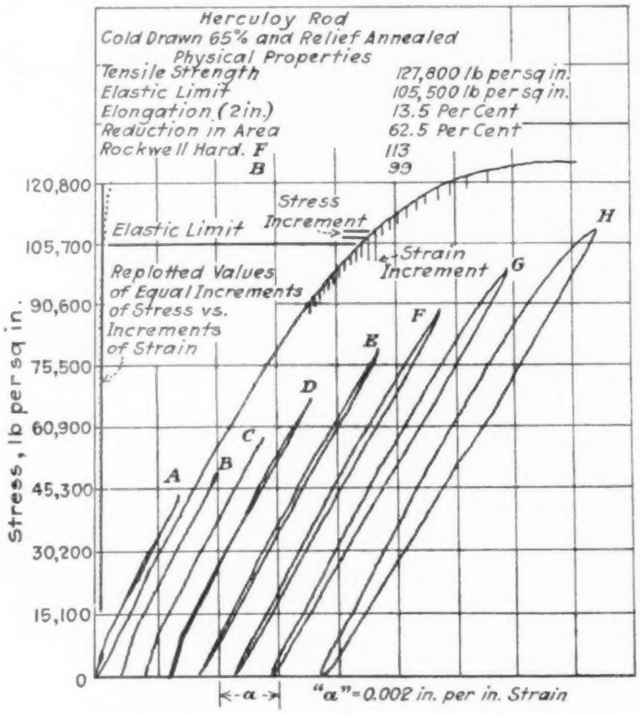

FIG. 6 ELASTICITY CHARACTERISTICS, COPPER-SILICON ALLOY (Curve *A*, 45,000 lb per sq in.; *B*, 50,000; *C*, 60,000; *D*, 70,000; *E*, 80,000; *F*, 90,000; *G*, 100,000; *H*, 110,000. Sample loaded to these stresses and loads released in order listed. A second sample was used for the stress-strain curve and elastic-limit determination. Each curve has its own zero point.)

In the construction of corrosion-resisting equipment, relief-annealed material should be used, and when additional severe cold-working is an incident to construction, adequate steps should be taken to relieve the member of any excessive stresses that may have been introduced by such cold-working. In ordering products made of the modified brasses, such as Naval brass, manganese bronze, and similar alloys, the engineer should avoid specifying physical properties which represent maxima attainable only through extreme cold-working of such alloys. It is seldom possible to retain such maxima in adequately relief-annealed products. Attempts to utilize such products in the extreme hard-worked condition are likely to result in failures having their origin in stress-corrosion cracking (90, 106, 110, 111, 112).

It is also pointed out in the foregoing connections that hard-drawn copper-base alloys are peculiarly sensitive to the so-called "notch effect" in so far as fatigue resistance is concerned, and that this sensitivity is drastically reduced by relief annealing.

Where corrosion fatigue presents a possible source of failure, it should be remembered that in general the hot-rolled nonferrous alloys have a much higher endurance limit in fatigue than the same alloys produced by extrusion methods. Thus, hot rolling should be specified as the method of fabricating such alloys whenever a maximum resistance to fatigue is desired and the alloys are of such nature that it is possible to fabricate them by such method (107).

The mechanical design of a structure often determines its ability to withstand corrosion. Problems in design, if improperly handled, may result in rapid failure of a structure, under conditions of corrosion, that otherwise would, if the design were properly handled, give long and satisfactory service.

Failures of this kind are, of course, not peculiar to copper and the copper-base alloys, and the precautions in design necessary to be observed in connection with constructions employing copper and its alloys are in general the same as those which must be observed in connection with the employment of other structural corrosion-resisting materials.

It is widely recognized that dissimilar metals in contact are a frequent source of destructive corrosion. Failure of this type may result when copper, as a sheathing or lining material, is joined by soft-soldering. Soldered joints are often the foci of corrosive attack and pitting, and line corrosion of the copper adjacent to the joint can and does in many cases cause failure (90). In general, in the case of roofing and similar applications of sheet copper, it is recommended that the presence of soldered joints be reduced to a minimum, and that, so far as used, care be taken in the selection of soldering fluxes and highly acid fluxes be avoided (107, 113).

In tank constructions employing sheet copper, various possible methods of joining the sheets are presented. Riveting, frequently in combination with soft-soldering, or brazing with hard solders, such as high zinc-copper alloys, is a method frequently employed. Other frequently utilized methods are brazing with materials of the Naval-brass type and brazing or welding with the phosphor bronzes or the silicon-copper alloys.

It is also possible to obtain joints that are substantially autogenous in character through brazing with certain silver-copper alloys and copper of high phosphorus content.

The engineer should give careful attention to the joining method adopted, with particular reference to the chemical activity at the joint that might be anticipated in the handling of a specific material.

Further, with reference to tanks and the like, it should be observed that one of the advantages offered by the silicon-copper alloys is that they can be so readily fabricated by autogenous welding, with the consequent elimination of corrosion problems incidental to the presence of dissimilar metals in contact.

With copper, as with any other sheathing or lining material, the lack of proper provision for expansion and contraction of the metal with temperature changes can lead to cracking and other forms of corrosion-fatigue failure. Adequate provision for such expansion and contraction should be made, particularly in the design of structures utilizing extended areas of copper as a sheathing or lining material, and particularly in the case of copper roofing.

It is true of copper and its alloys, as it is true of other corrosion-resisting materials, that impingement corrosion will frequently cause failure in cases where the material of construction is otherwise ordinarily immune to the action of the corrosive material involved. The structural design should be so controlled, when possible, as to eliminate impingement attack entirely, or to reduce it to a minimum. When impingement corrosion is anticipated, protection or reinforcement should be

incorporated in the design to avoid, so far as is possible, the consequence of this effect.

There is probably no field of use where impingement is such a factor in determining the ultimate life of the material as in the condenser tube (114). It is to their excellent ability to resist impingement attack that the cupronickels and the aluminum brasses owe their success in the condenser-tube field.

While it is necessary in the design of corrosion-resisting structures to consider, as has been suggested, many mechanical factors that may be involved in the corrosion problem, it is also frequently necessary carefully to weigh the probable effect of minor variations in the composition of materials to be handled. For example, the literature and data referred to herein give extensive information as to the resistance to sea-water corrosion of most of the commonly available structural materials. "Sea water" is, however, a large and comprehensive term, and the corrosive nature of sea water varies considerably with the location in which it is found. Cold, north-Atlantic water, the warm waters of the tropical seas, the polluted harbor waters adjacent to industrial cities and large ports, and the brackish waters of tidal streams, all present different problems. A material which will satisfactorily withstand the corrosive attack of cold, clean, north-Atlantic water may fail quickly and completely when exposed to harbor water contaminated by industrial wastes.

A more striking illustration of the influence of minor constituents or impurities is to be found in our industrial and domestic fresh-water supplies. There are sections of the country where the water supplies are such that there is no apparent economic advantage in the use of nonferrous pipe. There are other sections of the country where the waters are of such a nature that there is a definite economic advantage in the use of brass or copper pipe. However, even in these latter cases, there is a considerable variation, and there are known water supplies where ordinary high-zinc brasses do not give adequate life and with which it is necessary to use 85/15 or red-brass pipe or else copper tube. Then, we have extreme cases where industrial and domestic water supplies are characterized by low permanent hardnesses in combination with a high CO_2 content, and such waters will attack to some degree practically every available commercial metal. In such extreme cases we find rapid destruction of some types of pipe, and a corrosive action which would constitute a hazard to health if certain other types were employed, and the water even on red brass and copper would have sufficient chemical activity to cause an objectionable green staining of plumbing fixtures and at times a slight discoloration of the water. In such extreme cases tinned-copper tubing is recommended (115, 116).

The foregoing instances are cited primarily to illustrate the necessity of considering factors which at first glance might appear to be unimportant, but which, as a matter of fact, may constitute the direct cause of corrosion failure and unsatisfactory service if their probable effect is not anticipated by the engineer.

This paper has attempted to point out the salient characteristics, both chemical and physical, of copper and its principal alloys. Because of the breadth of the subject, it has been impossible to dwell in detail on the properties and characteristics of any specific alloy, or on the detail of conditions presented in any specific application. It is hoped, however, that the general information given herein, together with the larger information available in the appended references, will serve to give the designing engineer a more comprehensive knowledge of the wide range of structural materials made available to him by copper and its alloys. It is also hoped that the brief suggestions advanced in respect to design and mechanical factors and operating conditions will in analogous cases be helpful in suggesting to the engineer points of investigation pertinent to his particular problem, and will on occasion lead him to invite the cooperation and consultation of the technicians within the industry, who are held available for such consultation by practically all of the manufacturers of copper and its products.

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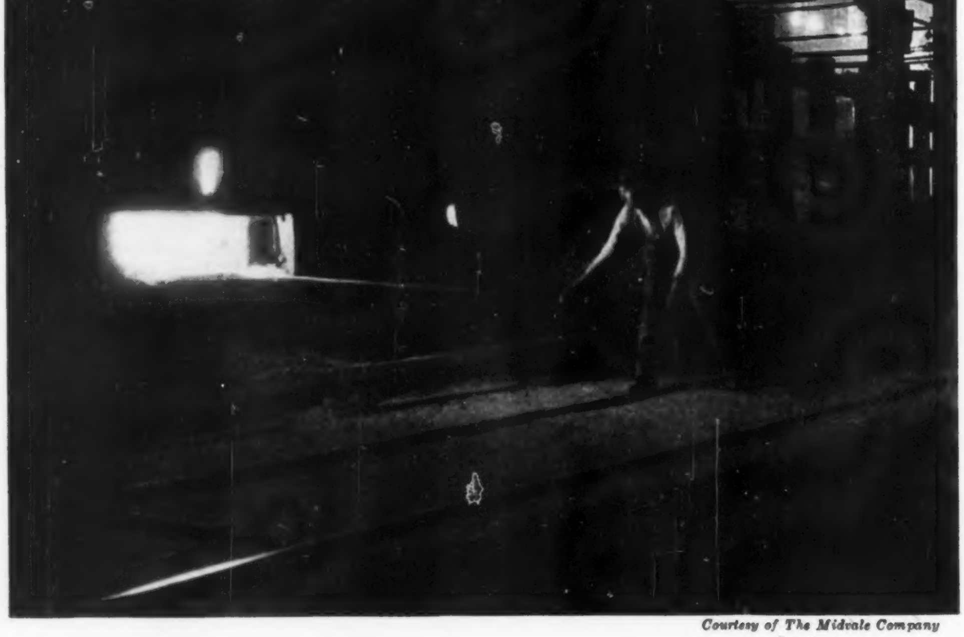

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Corrosion-Resistant STAINLESS STEELS *and* IRONS

By J. H. CRITCHETT

UNION CARBIDE AND CARBON RESEARCH LABORATORIES, NEW YORK, N. Y.

THE RESULTS that can be expected from the use of a corrosion-resistant material, whether it be of a steel or nonferrous variety, depend so much upon the conditions of use that it is practically impossible to give concrete and specific advice concerning the choice of the most suitable material without very full and detailed information about the application. The means of fabrication, the other materials that will be assembled in connection with the apparatus, the minor impurities that may creep into the system, and many other factors affect the final life of the equipment to a degree that may vitiate judgment based only on composition. Attempt is made in the present paper to lay a foundation for the selection of a proper quality of stainless steel, based on a combination of laboratory tests and practical results achieved in application.

The corrosion-resistant stainless steels and irons are a rather recent development, but their growth has been quite remarkable and they are playing an ever-increasing rôle in industry. The steels were developed practically simultaneously in England by Brearley, in Germany by Strauss, and in the United States by Haynes, Becket Johnson, and others. Undoubtedly, the credit for the first development should go to Brearley, since his type of stainless steel was the first to be put on the market in a commercial way. That the development was going on concurrently in so many places, however, is an indication both that the need for such steels had arisen in the rapidly developing field of chemical engineering and that the materials required for their production had been developed to a satisfactory commercial state.

CHROMIUM THE ESSENTIAL ALLOYING ELEMENT OF STAINLESS STEELS

It is significant that all of the stainless steels depend on the presence of chromium for their major corrosion-resistant properties and that to date no other element has been found which can be added to the steel in the same or lower proportions to achieve the same result. Fortunately, chromium is one of the most available and plentiful of the alloying elements and also is included in the group of lower-cost alloying metals.

Evans, in England, and others have shown that the corrosion resistance of chromium steels is undoubtedly due to the formation of a thin, adherent, continuous film of chromium oxide. If this film hypothesis is true, and certainly all of the results and experiences can well be explained by it, it follows that chromium steels will show the greatest corrosion resistance under oxidizing conditions, that is, in situations where oxygen is available for production of the film. It follows further that the corrosion resistance will be reduced or completely eliminated in situations that enable the removal of this film by chemical solution or by combined abrasion and corrosion. Other elements may be added to the chromium steels either to improve their physical properties or corrosion resistance, or for both purposes. It is perhaps logical to expect that the addition to the chromium steels of certain elements or metals which have a specific resistance to the nonoxidizing acids and chemical reagents would improve the resistance of the steel to the chemicals to which the addition agent itself is resistant. Molybdenum, for instance, is quite resistant to hydrochloric acid, and its addition to the stainless steels is very helpful for service where solutions containing very small amounts of hydrochloric acid must be handled. Nickel is quite resistant to some of the mineral acids and to many of the organic chemicals, and its addition to the chromium steels increases their resistance to such corroding media. Copper is quite resistant to carbonic acid in mild concentrations; hence, its addition to the chromium steels leads to better resistance to atmospheric and to certain other moderately weak acid conditions. This paper considers principally the corrosion-resistant properties of the various grades of chromium steels and the rôle of addition agents in modifying these properties.

PHYSICAL PROPERTIES OF STAINLESS STEELS

In spite of the intentional emphasis in this paper on the purely corrosion-resistant phase of the stainless steels, no mechanical engineer can start work without a knowledge of the physical properties of his materials; hence, these must be indicated. Table 1 summarizes the usual information for the various grades of steel that will be discussed later from the corrosion point of view. It must be strongly emphasized that the values given are only typical. Slight modifications of composition, variations of heat-treatment, and the effect of cold work among other things may vary the values over a range nearly as great as we are familiar with in carbon steels with little or no effect on the corrosion resistance.

There is another reason also for injecting the question of physical properties. It will be noted that the values in the table are relatively high. Particular emphasis should be given to the peculiarly high ductility values that in many instances accompany high yield point and ultimate strength. Ductility is of course an important element of safety in any structure, especially one subjected to shock or complex stresses; hence, the stainless steels are well adapted to engineering construction. The high strength of the steels enables the use of high unit stresses and hence light sections. In fact, in many applications the use of a properly conservative high unit stress has resulted in such light sections that they could not have been considered because of the danger from rusting, were it not for the corrosion resistance of the chromium steels. Thus an entirely new and modern type of construction is growing up, based on these steels, that is exceedingly light and yet permanent because of the nonrusting characteristic. The possibilities involved in such construction are most stimulating to the engineer. Its development calls for the most thorough knowledge of elements of design and freedom from the constraint of precedent. The opportunity to use originality and sound judg-

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TABLE 1 TYPICAL PHYSICAL PROPERTIES OF VARIOUS ANNEALED CORROSION-RESISTANT STEELS

Analysis, per cent: Cr	C	Ni	Mo	Other	Yield point, 1000 lb per sq in.	Ultimate strength, 1000 lb per sq in.	Elongation in 2 in., per cent	Reduction of area, per cent	Erichsen, mm	Creep strength at 700 C, 1000 lb per sq in.
1	0.10 (As rolled)	..	...	Cu, Si, P	60	75	25	60	...	...
5	0.10	..	0.5	...	65	85	30	75	...	...
13[a]	0.10	..	...	...	40	75	30	60	7.5	...
18[b]	0.10	..	...	...	50	80	25	45	8	...
18	0.15 (Heat-treated)	2	...	...	140	175	15	50	..	...
18[b]	0.10	..	...	8 Mn 1 Cu	50	100	45	55	11	...
18[c]	0.08	8	...	...	40	85	60	60	13	4
18[b]	0.08	8	2.5	Cu	40	85	60	60	12	8
25	0.20	..	...	...	50	80	25	45	...	0.8
25	0.20	12	...	...	50	100	55	55	...	5
25	0.20	20	...	...	50	100	50	55	...	5.2

[a] Frequently used in heat-treated condition with much higher yield point and ultimate strength.
[b] Frequently used in cold-rolled condition with much higher yield point and ultimate strength.
[c] Frequently used in cold-rolled condition with yield point of 150,000 lb per sq in., ultimate strength of 180,000, and elongation of 10 per cent.

ment in the development of this type of construction is obvious; this period we are now entering may well mark another major advance in engineering practice, of which the development of the steam engine and railroad building are examples.

STAINLESS STEELS CLASSIFIED ON BASIS OF CHROMIUM CONTENT

Reverting to the corrosion resistance, which is the unique property of the steels in which we are interested, we shall first classify them broadly and then discuss each class in greater detail. The first broad group includes the plain chromium steels. They may be roughly divided into classes containing approximately, 1, 5, 8, 12, 18, 25, and 35 per cent of chromium. The chemical resistance of the chromium steels is a direct but far from linear function of the chromium content of these steels. For instance, there is an abrupt change in the curve of resistance as we pass about 11 per cent chromium, so that those steels containing 12 per cent of the element are markedly superior to those of lesser content. Again, at about 22 per cent chromium there is another marked break in the curve, and steels containing in the neighborhood of 25 per cent chromium are again markedly superior to those of lower content for many uses. This generalization is accurately true for resistance to strong oxidizing agents, such as nitric acid, products of combustion, and many other analogous corroding media. However, the presence of other chemicals or gases may distinctly modify the situation, so that extreme care should be taken to determine fully all of the conditions surrounding the use in applying the steels.

STAINLESS STEELS CONTAINING NICKEL

The next general group includes the chromium steels modified with nickel, of which the so-called 18-8 variety is best known. Nickel in this class of steels increases corrosion resistance against chemical reagents which are only moderately oxidizing in character and atmospheres containing minute but important quantities of carbon dioxide, salt water, and sulphur dioxide. For example, the plain chromium steels are quite readily attacked by a 10 per cent oxalic-acid solution, whereas a chromium-nickel steel of the 25 per cent chromium–20 per cent nickel variety is so slightly attacked by this acid that it may be called completely resistant. Concentrated lactic acid attacks plain chromium steel but not the 18 per cent chromium–8 per cent nickel analysis. In this broad classification of chromium-nickel steels there is a large number of widely used commercial varieties. Chromium may range from approximately 10 to 30 per cent and the nickel from 8 to 35 per cent. In general, the greater the total alloy content, the greater the resistance to some types of corrosion, but the choice of higher nickel or higher chromium content depends on the specific conditions of service. Thus, if the conditions lean toward the oxidizing side, chromium should be well in excess of nickel. Illustrations are the popular 18–8 and 25–12, where the first figure in each instance indicates the chromium content. Where conditions are highly reducing, as for example, sulphurous acid under pressure at elevated temperatures, nickel should exceed the chromium.

CHROMIUM-MANGANESE STEELS

The chromium-manganese steels typified by the 18 per cent chromium–8 per cent manganese variety is the next broad group. In general, manganese in this group of steels plays a rôle similar to that of nickel in the chromium-nickel steels. Metallurgically, it performs identically the same function and, chemically, it confers properties that differ from those of the chromium-nickel variety of steels, as might be expected, from its own properties. It is less effective against certain media and more effective against others. For example, where sulphurous gases are involved or where hydrogen sulphide or similar reducing acids are present in solution, manganese affords greater protection than nickel. On the other hand, where chlorides and certain organic acids must be resisted, nickel confers properties superior to those conferred by the manganese.

OTHER ALLOYING ELEMENTS

So much for the broad groups. All are modified as to their chemical resistance, physical properties, or fabricating characteristics by additions such as molybdenum, tungsten, vanadium, copper, silicon, aluminum, titanium, columbium, nitrogen, zirconium sulphide, selenium, and others either singly or in combination. Molybdenum, tungsten, and vanadium are used particularly to increase the mechanical properties, more especially strength at high temperature. Molybdenum is also something of a specific against corroding media containing chlorides and sulphites. Copper is quite widely used in many varieties of stainless steel to tone up generally their corrosion resistance, particularly against carbonic acid and other weak organic acids. Silicon and aluminum not only affect physical properties, but are particularly useful where high temperatures and the corrosive action of products of combustion must be met. Titanium and columbium increase the general corrosion resistance in that they liberate chromium from carbides, thus increasing the effective chromium content. In addition, columbium in particular markedly affects physical properties, such as ductility and deep drawing, and is exceedingly beneficial where the steels are to be used at high temperature or where fabrication will be by welding. Nitrogen increases the yield point without proportionately increasing brittleness, and materially affects grain size, with a resultant improvement in shock resistance

and other physical properties. Zirconium sulphide and selenium are added to confer free-machining properties to the steel where it is intended to be fabricated into bolts and other parts requiring a large amount of machine work.

Next let us describe somewhat more specifically the subdivision of the broad groups.

CHROMIUM STEELS

The 1 per cent chromium steels, with or without additions of copper, silicon, or phosphorus, are in no sense to be considered as stainless. However, the rate of corrosion of this class of steels under most atmospheric conditions is definitely lowered, so that the life of structures produced from them is increased an appreciable degree. Moreover, the slower rate of corrosion enables the designing engineer to take full advantage of the increased strength of this class of steel.

The 4 to 6 per cent chromium steels show still further reduction in the rate of corrosion under atmospheric conditions and are quite resistant to crude oil and distillates at the moderately elevated temperatures encountered in oil cracking. These steels, with low carbon content, are widely used as tubes, valves, and fittings in the oil industry. With somewhat higher carbon content, a fair degree of abrasion resistance is added to the corrosion resistance, and the steels find application in dredge parts and the like. This class of steel is markedly improved by the addition of molybdenum or tungsten. The general corrosion resistance is somewhat increased, but in particular the strength at high temperatures is augmented and the rate of creep reduced. Columbium increases the corrosion resistance of these steels by taking unto itself all of the carbon present and for the same reason greatly reduces the air-hardening properties so as to make much easier fabrication where the work must be done hot.

The very special group of steels containing approximately 8 per cent of chromium, with several per cent of silicon, with or without aluminum, has found wide use as valve steels against combustion gases. Their use in automotive and airplane engines is undoubtedly quite familiar. They are similarly used in many other applications and, although the tonnage is not large, are a very important element in modern engineering design.

At 12 per cent chromium we first arrive at an analysis which can be considered stainless in the very general and common meaning of the term. The steels in this class are readily fabricated, although as is the case with practically all of the steels under discussion in this paper, and in particular the straight chromium steels, more care and knowledge are required in their welding than are necessary for the ordinary plain low-carbon steels. They are resistant to general corrosion to a large extent, but require protection if a bright mirror surface is to be preserved. They are resistant to acids such as weak phosphoric, boric, and many of the inorganic acids, as well as alkalies and alkaline salts.

The 15 and, in particular, the 18 per cent low-carbon chromium steels have much better resistance to atmospheric conditions, and for this reason are recommended where, as in much interior architectural work, a bright surface is desired. They find extensive application in chemical-plant construction, especially in that for manufacturing or using nitric acid. With increased carbon content the 15 to 18 per cent chromium steels are commonly known to most of us as cutlery. In the heat-treated and polished condition they are resistant to various fruit and vegetable acids; hence widely used in households and restaurants. Another variety of the 18 per cent chromium steel, containing 1 or 2 per cent of nickel, may be heat-treated to a very high strength and is the standard steel for British aircraft, under their famous specification S-80. In the heat-treated condition the steel is quite free from general corrosion as well as pitting under normal aircraft service. This class of steels is often modified to advantage by additions of copper, silicon, nitrogen, or columbium, the effects of these various elements being those that have been previously described in this article.

The 25 per cent chromium steels not only have improved general corrosion resistance, but also are exceedingly resistant to oxidation at elevated temperatures. While not the most easily fabricated of the stainless steels, they are regularly produced in the common forms of sheet and tubing. They find wide service in the handling of superheated steam and food products, and, in particular, as furnace muffles, annealing boxes, and similar applications where temperatures are lower than about 900 C. The addition of nitrogen, especially in the presence of a small amount of nickel, to this analysis definitely refines the grain, improves its shock resistance, and materially reduces the rate of grain growth at high temperature, which is one of the properties that must be watched in a truly ferritic steel of this type.

18–8 CHROMIUM-MANGANESE STEELS

Passing from the plain chromium steels, the next in order of increasing corrosion resistance is the 18 per cent chromium–8 per cent manganese variety. These steels are definitely more corrosion resistant than the straight 18 per cent chromium variety. Usually they carry approximately 1 per cent of copper, and this analysis is the equal of the 18 per cent chromium–8 per cent nickel variety in many applications where hot gases involving hydrogen sulphide and sulphur dioxide are present. In some other types of corrosion, such as that encountered in certain mineral waters and solutions containing sulphites, the performance of this steel is definitely better than that of the 18 per cent chromium–8 per cent nickel variety. Tests in moist air at 92 per cent humidity proved this steel eminently suited to such service. The resistance to fruit juices is particularly good. The strength at high temperature of these chromium-manganese steels is somewhat less than that of the chromium-nickel. While a disadvantage in some uses, this property is a distinct advantage in the manufacture of the steel, since it means greater ease of rolling. Moreover, the deoxidizing and cleansing action of the manganese during the process of manufacture is very helpful in holding nonmetallic inclusions to a minimum, which is especially important in the high-quality stainless steels.

18–8 CHROMIUM-NICKEL STEELS

The 18 per cent chromium–8 per cent nickel steels represent by far the most popular of all the stainless varieties. This deserving popularity results from a combination of great general corrosion resistance and remarkable physical properties. These steels are readily rolled, so that they may be obtained in all of the usual forms in which rolled steel is supplied, fabricate without difficulty, and, when the carbon is adequately combined with columbium or titanium, present no difficulties in welding. Their ductility is very high, allowing deep-drawing operations to be performed with ease. They readily cold-work, thus making it possible to obtain a very high yield point and ultimate strength without proportionate loss of ductility. Not only are the 18–8 chromium-nickel steels resistant to practically all of the media to which straight 18 per cent chromium steels are resistant, but in addition show excellent resistance to boiling lactic and phosphoric acids in low concentrations and to high concentrations of oxalic acids and many other organic materials.

TABLE 2 PURE MEDIA AND CONDITIONS FOR PRACTICALLY COMPLETE CORROSION RESISTANCE OF VARIOUS LOW-CARBON STAINLESS STEELS

Media	Conc, per cent	Temp, C	Percentage of alloying elements: 13 Cr	18 Cr	25 Cr	Cr-Mn-Cu 18-8-1	Cr-Ni 18-8	Cr-Ni 25-20	Cr-Ni-Mo-Cu 18-8-2.5-1.5
HNO_3	10	20	x	x	x	x	x	x	x
H_3PO_4	10	20	x	x	x	x	x	x	x
Formic	10	20	x	x	x	x	x	x	x
Acetic	10–50	20	x	x	x	x	x	x	x
Acetic	Glacial	20	x	x	x	x	x	x	x
Tannic	10	100	x	x	x	x	x	x	x
Phenol	10	100	x	x	x	x	x	x	x
Na_2CO_3	10	100	x	x	x	x	x	x	x
Pb acetate	25	100	x	x	x	x	x	x	x
KNO_3	50	100	x	x	x	x	x	x	x
Cr_2SO_4	Sat.	100	x	x	x	x	x	x	x
$ZnCl_2$	1.2 d.	20	x	x	x	x	x	x	x
HNO_3	30	20	...	x	x	x	x	x	x
Formic	30	20	...	x	x	x	x	x	x
Citric	10	20	...	x	x	x	x	x	x
NH_4NO_3	Sat.	100	...	x	x	x	x	x	x
Atmospheric	General	...	...	x	x	x	x	x	x
Atmospheric	Under	900	...	x	x	...	...	x	...
HNO_3	10	100	...	x	x	x	x	x	x
HNO_3	Conc.	20	...	x	x	x	x	x	x
Atmospheric	Above	900	...	...	x	...	...	x	...
Furnace gases	Under	900	...	...	x	x	...	x	...
Mine waters		20	...	...	x	...	...	x	...
Sulphur-compound gases	Under	900	...	...	x	x	...	...	...
Flue gases	....	...	...	...	...	x	x	x	x
Mineral waters	(S)	20	...	...	...	x	...	...	...
Lactic	1.5	100	...	...	...	x	x	x	x
Oxalic	10	20	...	...	...	x	x	x	x
Salt spray	....	20	...	...	...	...	...	x	...
Furnace gases (reducing)	....	950	...	...	...	...	...	x	x
Sulphite liquors	....	...	...	...	...	...	...	...	x
Sea water	....	...	...	...	...	...	...	...	x
$FeCl_3$	Low	20	...	...	...	...	...	...	x

This class of steels is used widely, in addition to those places where corrosion resistance is the prime requisite, in many places where strength and permanence are the chief requirements. Thus, many strength- and pressure-resistant members in the chemical industry are made from this steel. Many trucks travel our roads with increased load-carrying capacity because of the use of this type of steel. A number of the epoch-making light-weight trains that are creating so much interest on the railroads are of very highly specialized design made possible by this class of steel. In this category aircraft and many other elements in the transportation industry could be included if space permitted. They are used widely for decorative purposes, in addition to fulfilling a large number of miscellaneous applications, from cooking pots to marine hardware.

There are numerous modifications of the common 18 per cent chromium–8 per cent nickel analysis, molybdenum perhaps being the most frequent. Copper is often found in the commercial grades of this analysis; titanium and columbium are widely used to stabilize it for use at high temperature, and many other modifications have been made to adapt it to particular uses. Where service is more severe, this analysis is improved by simple increase of both chromium and nickel, a common and useful analysis being 25 per cent chromium–12 per cent nickel.

STEEL WITH HIGH ALLOY CONTENT

The list of steels of higher alloy content suited to special performances is so long as to prohibit comprehensive description. Such analyses as 25 per cent chromium–20 per cent nickel, 30 per cent chromium–25 per cent nickel, 25 per cent nickel–15 per cent chromium, 35 per cent nickel–18 per cent chromium, are common, and all of these compositions are modified on occasion, usually with the elements that have already been described and with results that could be predicted on the basis of earlier explanations of the functions of these metals. While relatively expensive, this group of steels finds application where chemical attack is particularly severe or very high temperatures encountered. For example, they are widely used in the form of carburizing and annealing boxes and furnace parts at temperatures in excess of 850 C. Special parts for handling superheated steam at high pressure and temperature, such as valves and fittings, are often made from compositions in this category.

Perhaps special attention should be given to that modification of the 18 per cent chromium–8 per cent nickel, or 25 per cent chromium–12 per cent nickel which contains molybdenum, copper, and columbium. When so modified, the steels have a noticeably increased general corrosion resistance but, in particular, seem to be much more resistant to the pitting type of corrosion, where sea water, minute quantities of hydrochloric acid, high concentrations of lactic acid, and such special compounds as aluminum sulphate or zinc chloride are present in boiling solution. While somewhat new in the field of stainless steels, this modified variety of 18–8 is likely to find an exceedingly wide use.

RESISTANCE TO SPECIFIC MEDIA

It will be recognized from the foregoing that there is no stainless steel resistant to all corrosion media, and that the corrosion resistance of a given steel to a given application can only be predicted if all of the factors involved in the fabrication, assembly, and maintenance of the equipment are known, in addition to the details of the corroding media and the way they change in the processes involved. Table 2 is based largely on laboratory experiments performed in all parts of the world as they have been confirmed by experience with actual plant installations. The author has attempted to cull the data, giving only that which in the opinion of the majority is definitely reliable.

It will readily be noted that the data follow the form of a triangle, which results naturally from the fact previously mentioned—that increased alloy content tends toward increased corrosion resistance. The choice of the steel for a given application depends on corrosion resistance, physical properties, ease of fabrication, and cost. Corrosion resistance is only one factor. In some cases it may be the predominating factor, but in most instances a decision can only be made after a study of all the factors and the conclusions arrived at by the balancing and weighing of these factors by engineers of experience and judgment.

NICKEL *and* NICKEL-BASE ALLOYS

Their Use in the Design of Corrosion-Resistant Machinery and Equipment

By F. L. LaQUE

DEVELOPMENT AND RESEARCH DIVISION, INTERNATIONAL NICKEL COMPANY, INC., NEW YORK, N. Y.

THE MATERIALS to be covered by this contribution to the symposium on corrosion-resistant metals are the following:

1 Pure nickel; including nickel-clad steel
2 Monel; including regular Monel; K-Monel, that can be hardened by heat-treatment; and two special varieties of cast Monel having extra hardness, and known as grades H and S.
3 Inconel; including Inconel-clad steel
4 The Hastelloys A, C, and D
5 Illium.

On this continent, at least, these materials constitute the commercially most important of the metals and alloys that may properly be discussed under the title of this paper. Reference should be made to other papers in the symposium for data on other nickel alloys included in the copper-base-alloy, corrosion-resistant (stainless) steel, low-alloy-steel, and alloy-cast-iron groups.

In addition to these materials which will be discussed in some detail, attention is directed to a recently developed corrosion-resistant, hard-surfacing material known as Colmonoy, the No. 6 grade of which has a nickel base (about 75 per cent nickel). Another essential constituent is chromium boride. This material produces deposits having a hardness of 58 to 60 Rockwell C (545 to 575 Brinell), and the deposits are resistant to mineral and organic acids and to alkalies. The coating material may be deposited by oxyacetylene or metallic-arc welding, or may be cast on by pouring the molten alloy at from 2350 to 2500 F into a suitable mold containing the base metal preheated to from 1200 to 1400 F. Colmonoy No. 6 is used for pump sleeves, pump rods, cam collars, etc., and for plug cocks to counteract galling or seizing tendencies.

There are available a number of alloys containing from 60 to 80 per cent nickel and from 13 to 20 per cent chromium, with the remainder mostly iron, which are used principally for heat-resisting purposes. In general, their corrosion-resisting characteristics are similar to those of Inconel, the notes on which may be used as a guide to their probable usefulness in chemical equipment.

Chemical compositions of the several materials under consideration are shown in Table 1.

Data on the physical constants of the materials are given in Table 2.

The mechanical properties for which reliable data are available are tabulated for each material in Tables 3 to 8, inclusive.

Some data on the effects of temperature on the properties of Monel, nickel, Inconel, and Hastelloy A are given in Tables 9 and 10.

The forms in which the several materials are available are shown in Table 11.

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It will be noted from the data on mechanical properties that all of the high-nickel alloys under discussion are strong. In fact, high-strength regular Monel and K-Monel possess mechanical properties comparable with those of high-strength alloy steels. It is noteworthy also, that these high-nickel alloys retain their strength, ductility, and toughness over a wide range of temperature conditions. While good mechanical properties are important, the principal considerations leading to the use of these materials in industry are almost invariably based on their ability to endure when exposed in corrosive environments and to retain their mechanical properties under severe service conditions.

The limits of usefulness of a corrosion-resisting material cannot be defined as precisely as its mechanical properties, since resistance to corrosion is governed by complex factors, many of which pertain to the environment rather than to the material, and which are difficult to estimate and often impossible to control. The following sections of this paper will be devoted to a general outline of the corrosion-resisting characteristics of each material, separately, illustrated by appropriate supporting data.

In citing corrosion data, two terms may be used in expressing corrosion rates, first, weight loss expressed in milligrams per square decimeter per day (24 hours), often abbreviated mdd, and, second, inches penetration per year, abbreviated ipy, which means the depth to which uniform corrosion would penetrate if the material were exposed to corrosion on one side only continuously for 365 days of 24 hours each.

CORROSION-RESISTING CHARACTERISTICS OF NICKEL

Nickel is a relatively noble element; in the physical chemists' electromotive series it is shown to be 0.21 volt more noble than iron. The practical significance of this is that nickel does not readily discharge hydrogen from any of the common acids with which it may be used, and any corrosion that occurs requires a supply of some oxidizing agent, such as dissolved air, in order for corrosion to proceed. As a general rule, oxidizing conditions favor corrosion of nickel, while reducing conditions retard corrosion. However, nickel also has the ability to protect itself against certain forms of attack by the development of a corrosion-resisting or passive oxide film; as a result, oxidizing conditions do not invariably accelerate corrosion.

In order to facilitate discussion, the behavior of nickel and the other materials covered by this paper will be treated under several headings referring to particular types of exposure and corrosives.

ATMOSPHERIC CORROSION

One of the earliest uses of nickel was in the form of plating to protect other and more vulnerable materials from atmospheric corrosion and tarnishing. This remains an important application of the metal.

Recent tests completed by the American Electroplaters' Society, the American Society for Testing Materials, and the

TABLE 1 APPROXIMATE COMPOSITIONS

Material	Nickel, per cent	Copper, per cent	Iron, per cent	Chromium, per cent	Molybdenum, per cent	Aluminum, per cent	Silicon, per cent	Manganese, per cent	Tungsten, per cent	Carbon, per cent
Nickel	99.4[a]	0.1	0.15	..	..	...	0.1	0.15	...	0.1
Monel	68	29	1.5	..	..	...	0.1	1.1	...	0.15
H-Monel[b]	65	29	2	..	..	...	2.75	0.7	...	0.2
S-Monel[b]	64	29	2.5	..	..	...	3.75	0.5	...	0.1
K-Monel	63	31	1.5	..	..	3.5	0.2	0.50	...	....
Inconel	79	..	7	13	..	...	....	....	...	....
Hastelloy A	58	..	20	..	20	...	....	2	...	....
Hastelloy C[b]	58	..	6	14	17	...	....	....	5	....
Hastelloy D[b]	85	3	....	..	..	2	10	....	...	....
Illium[b]	56	8	....	24	4	...	1	1.5	2	....

[a] Including cobalt. [b] Available only in cast form.

TABLE 2 PHYSICAL CONSTANTS

Material	Density	Lb per cu in.	Melting point, F	Specific heat, 80–750 F	Coefficient of thermal expansion per deg F, 80–212 F	Thermal conductivity Btu per sq ft per ft per deg F per hr	Electrical resistivity, ohms per circular mil per ft at 32 F	Modulus of elasticity in tension	Modulus of elasticity in torsion
Nickel	8.85	0.319	2640	0.130	0.000007	34	63	30,000,000	11,000,000
Monel	8.80	0.318	2460	0.127	0.000008	15	256	26,000,000	9,500,000
K-Monel	8.58	0.310	2400–2460	0.127	0.000008	15	373	26,000,000	9,500,000
Inconel	8.55	0.309	2540	0.109	0.0000064	8	575	31,000,000	11,000,000
Hastelloy A	8.80	0.318	2372–2426	0 0939	0.0000081[a]	10	763	27,400,000	.....
Hastelloy C	8.94	0.323	2318–2381	0.0920	0.0000079[a]	7	800	.....	.....
Hastelloy D	7.80	0.282	2030–2048	0.1086	0.0000085[a]	12	681	28,850,000	.....
Illium	8.3	0.300	2372	0.105	0.0000075[b]	..	735	.....	.....

[a] 400–1100 F. [b] 80–575 F.

National Bureau of Standards[1] have established that the protective value of nickel coatings on steel depends almost entirely on their thickness. At least 0.0005 in. is required for good protection under mild conditions, and at least 0.001 in. for protection under severe conditions. Chromium plating adds little or nothing to the protective value of nickel plating when the customarily very thin (up to 0.00003 in.) deposits of chromium are used.

As a protection to steel, or other metals, in submerged exposure in corrosive environments, a minimum thickness of 0.002 in. of nickel plating is recommended. It is possible to control the physical properties of the deposited nickel, and nickel plating having a hardness equivalent to 400 Brinell has been used where wear resistance, as well as corrosion resistance, was required. It may be noted here that tests have indicated that an electrolytically plated coating of nickel 0.002 in. thick is equivalent in protective value to a spray-gun-deposited coating 0.020 in. thick, because of the greater porosity of the sprayed coatings.

Nickel and nickel plating will remain reasonably bright and free from tarnish indoors, being superior to silver, copper, and brass in this respect. It becomes dull when exposed outdoors and tends to acquire a very thin, adherent corrosion product which usually is a basic sulphate.

Actual corrosion of nickel in the atmosphere is practically nil in indoor exposure, while outdoors the rate of attack is extremely slow and varies with atmospheric conditions. Sulphurous atmospheres encountered in industrial and urban communities are naturally most corrosive. Marine atmospheres are scarcely more corrosive than suburban or rural atmospheres.

[1] Blum, Strausser, and Brenner, Research Paper RP-712, *Journal of Research*, National Bureau or Standards, vol. 13, September, 1934, p. 331.

An indication of the extent of what little corrosion occurs is provided by the results of the first three years of exposure of specimens of nickel strip in several typical atmospheres by Subcommittee 6 of Committee B-3 of the American Society for Testing Materials, reported in the Transactions of the society for 1935. These data are given in Table 12.

It is important also that experience has shown nickel to be free from season cracking and other forms of stress corrosion in atmospheric exposure.

FRESH-WATER CORROSION

Nickel possesses a very high degree of resistance to corrosion by natural waters and by distilled water. Analysis of distilled water from a nickel storage tank indicated a rate of corrosion of only 0.006 mdd or only 0.000001 ipy. Similarly, tests in natural waters have shown corrosion rates always less than 0.001 ipy, and usually less than 0.0001 ipy. Nickel is especially resistant to corrosion by waters containing hydrogen sulphide or free carbon dioxide.

Carbonated water is only slightly corrosive toward nickel. Analysis of water from a nickel-lined carbonator operated at a pressure of 200 lb per sq in. indicated a rate of corrosion of only 1.2 mdd, or 0.0002 ipy. It has been noted that in the presence of a high concentration of chlorides, as in one case 2000 ppm, carbonated water may cause pitting of nickel.

SALT-WATER CORROSION

Nickel is highly resistant to corrosion by sea water, the rates of attack being less than 0.005 ipy. Under conditions of agitation or flow of sea water, nickel may be used with good success. It may suffer local attack or pitting under conditions of stagnant exposure where barnacles or other solids may collect on the metal surface. It may be noted that nickel

TABLE 3 MECHANICAL PROPERTIES OF NICKEL

	Tensile strength, lb per sq in.	Yield strength, 0.5 % set, lb per sq in.	Elongation in 2 in., per cent	Reduction in area, per cent	Brinell hardness, 3000 kg
Cold-drawn rod and bar, annealed	65,000–85,000	20,000–30,000	50–35	75–65	110–150
Cold-drawn rod and bar, as drawn	80,000–115,000	60,000–90,000	35–15	65–50	140–230
Hot-rolled rod and bar	70,000–85,000	20,000–30,000	45–35	65–50	115–150
Forged rod and bar	75,000–105,000	50,000–80,000	40–20	...	130–210
Cold-drawn wire, annealed	80,000–95,000	....	...	...	...
Cold-drawn wire, regular temper	105,000–140,000	....	...	...	...
Cold-drawn wire, spring temper	140,000–175,000	....	...	...	...
Hot-rolled plate	65,000–80,000	15,000–25,000	45–35	...	110–140
Standard sheet	60,000–75,000	15,000–25,000	45–35	...	100–130
Cold-rolled sheet and strip, annealed	60,000–75,000	15,000–25,000	45–35	...	100–130
Cold-rolled sheet and strip, full hard	100,000–115,000	90,000–105,000	...	...	190–230
Cold-drawn seamless tubing, annealed	60,000–75,000	15,000–25,000	...	...	100–130
Cold-drawn seamless tubing, as drawn	80,000–95,000	50,000–60,000	25–15	...	140–170
Castings	60,000–75,000	20,000–30,000	35–15	50–30	100–130
Hot-rolled nickel-clad steel plates	55,000 min	27,500 min	27 min[a]	...	...

Notes: 1 Izod impact value for hot-rolled rod = 100 ft-lb.
2 Endurance limit annealed rod = 30,000 lb per sq in.
[a] In 8 in.

TABLE 4 MECHANICAL PROPERTIES OF MONEL

Form	Tensile strength, lb per sq in.	Yield strength, 0.5 % set, lb per sq in.	Elastic limit, lb per sq in.	Elongation in 2 in., per cent	Reduction in area, per cent	Brinell hardness, 3000 kg	Izod impact value, ft-lb
Cold-drawn rod and bar, annealed	70,000–85,000	25,000–35,000	20,000–30,000	50–35	75–65	130–165	120
Cold-drawn rod and bar, as drawn	85,000–125,000	60,000–95,000	45,000–75,000	35–15	65–50	165–270	75–115
Hot-rolled rod and bar	80,000–95,000	40,000–65,000	25,000–40,000	45–30	65–50	145–190	120
Forged rod and bar	80,000–110,000	60,000–85,000	45,000–65,000	40–20	70–50	145–240	75–115
Cold-drawn wire, annealed	70,000–85,000	25,000–35,000	20,000–30,000	...	...	...	....
Cold-drawn wire, regular temper	110,000–140,000	....	....	...	...	...	....
Cold-drawn wire, spring temper	140,000–175,000	....	....	...	...	...	....
Hot-rolled plate	60,000–75,000	25,000–35,000	20,000–30,000	35–25	65–50	115–150	....
Standard sheet	65,000–80,000	25,000–35,000	20,000–30,000	...	...	120–175	....
Cold-rolled sheet and strip, annealed	65,000–80,000	25,000–35,000	20,000–30,000	...	...	120–175	....
Cold-rolled sheet and strip, full hard	100,000–125,000	90,000–115,000	....	...	...	190–270	....
Cold-drawn seamless tubing, annealed	65,000–80,000	25,000–35,000	20,000–30,000	...	...	...	....
Cold-drawn seamless tubing, as drawn	90,000–105,000	60,000–75,000	....	...	...	...	....
Castings, regular	60,000–80,000	30,000–40,000	....	40–20	...	125–150	65–80
Castings, grade H	70,000–90,000	45,000–65,000	....	20–10	...	170–210	35–45
Castings, grade S	90,000–115,000	70,000–90,000	....	3–1	...	280–325	1–5

Endurance limit cold-drawn rod and bar, annealed = 37,000 lb per sq in.; as drawn = 53,000 lb per sq in.
Elastic limit in torsion cold-drawn wire, spring temper = 70,000 lb per sq in.

TABLE 5 MECHANICAL PROPERTIES OF K-MONEL

Treatment	Tensile strength, lb per sq in.	Yield strength, 0.5 % set, lb per sq in.	Proportional limit, lb per sq in.	Elongation, in 2 in., per cent	Brinell hardness, 3000 kg, softer than	Izod impact value, ft-lb
Hot-rolled and quenched[a]	120,000 max	80,000 max	60,000 max	40 min	225	115
Cold-rolled or cold-drawn after hot-rolling and quenching	120,000–140,000	80,000–100,000	60,000–80,000	30 min	225–275	80–115
Hot-rolled, quenched, and hardened by heat-treatment[b]	140,000–160,000	100,000–120,000	80,000–100,000	20 min	275–325	50–80
Cold-rolled or cold-drawn followed by hardening heat-treatment[b]	160,000 min	120,000 min	100,000 min	15 min	325 min	....

[a] Softening heat-treatment requires quenching in water or oil from 1425 F.
[b] Hardening heat-treatment requires holding for at least 8 hr at a temperature from 1075–1100 F followed by furnace or air cooling.

is nontoxic toward sea organisms and will not suppress the growth of barnacles.

NEUTRAL AND ALKALINE SALTS

Neutral and alkaline salt solutions, such as chlorides, carbonates, sulphates, nitrates, and acetates, are well resisted by nickel. Even under the most drastic conditions of temperature, agitation, and aeration, rates of attack are usually less than 0.005 ipy. Nickel tubes are being used successfully in sodium-chloride and sodium-sulphate evaporators, and more recently nickel-clad steel has been used for the construction of rotary salt driers.

The resistance of nickel to corrosion by sodium and calcium chlorides has been useful in connection with apparatus for cooling milk and other food products which require materials resistant to refrigeration brines, as well as to food acids.

TABLE 6 MECHANICAL PROPERTIES OF INCONEL

Form	Tensile strength, lb per sq in.	Yield strength, 0.5 % set, lb per sq in.	Elongation, in 2 in., per cent
Sheet and strip, annealed	80– 95,000	30– 40,000	55–45
Rod, annealed..........	80– 95,000	30– 40,000	55–45
Rod, cold-drawn........	100–130,000	80–105,000	30–20
Wire, annealed.........	80– 95,000	30– 40,000	55–45
Wire, spring temper....	175–200,000	......	...

NOTES TO TABLE 6:

1 Izod impact value annealed rod, 120 + ft-lb
2 Charpy impact value (standard 45 deg notch), 188 ft-lb
3 Endurance limit, cold-drawn rod as drawn, 44,000 lb per sq in.
4 Endurance limit, hot-rolled bar, 36,500 lb per sq in.
5 Elastic limit in torsion, cold-drawn wire, spring temper, 100,000 lb per sq in.

TABLE 8 PROPERTIES OF SPRINGS

Material	Torsional elastic limit, lb per sq in.	Torsional modulus	Maximum operating temp, F
Monel metal......	70,000	9,500,000	400
Nickel...........	65,000	11,000,000	400
Inconel..........	100,000	11,000,000	800

TABLE 7 MECHANICAL PROPERTIES OF HASTELLOYS AND ILLIUM

Metal	Form	Tensile strength, lb per sq in.	Yield strength, lb per sq in.	Elongation in 2 in., per cent	Reduction in area, per cent	Brinell hardness, 3000 kg	Izod impact value, ft-lb	Transverse breaking load, 12 in. span, lb
Hastelloy A	Forgings—annealed	110,000–120,000	47,000–52,000	48–30	54–35	210	62–77	...
Hastelloy A	Forgings—as forged	100,000–150,000	50,000–115,000	48–18	35–18	...	...	...
Hastelloy A	Castings	69,000–77,500	42,500–45,250	12–8	18–16	160	...	...
Hastelloy C	Castings	55,000–79,000	42,000–47,000	11–3	15–5	220	...	...
Hastelloy D	Castings	36,000–40,500	36,000–40,500	0	0	364	...	5,000
Illium	Castings	60,000	50,000	...	...	170–200	...	...

TABLE 9 RESULTS OF SHORT-TIME TENSION TESTS ON HOT-ROLLED RODS AT VARIOUS TEMPERATURES

Material	Temperature, F	Tensile strength, lb per sq in.	Yield strength, lb per sq in.	Elongation in 2 in., per cent	Izod impact value, ft-lb	Charpy impact value, ft-lb
Monel............................	−423	142,000	96,300	38.5	...	...
	−297	128,250	91,500	40	119	216
	70	90,000	67,000	31	119	216
Monel............................	70	85,000	45,000	45	...	...
	600	80,000	34,000	44	...	...
	800	70,000	30,000	40	...	...
	1000	55,000	27,000	30	...	...
	1200	36,000	23,000	18	...	...
Nickel............................	−292	98,000	....	..	98	...
	−112	76,500	....	..	92	...
	70	65,600	....	..	89	...
Nickel............................	70	81,000	25,000	54	...	...
	212	82,000	24,000	54	...	...
	392	83,000	23,000	54	...	...
	572	83,000	22,000	54	...	...
	842	78,000	20,500	54	...	...
	932	64,000	20,000	54	...	...
	1112	49,000	19,500	52	...	...
	1292	36,000	15,000	43	...	...
Inconel...........................	70	90,000	36,000	55	...	...
	600	90,000	35,000	55	...	...
	800	85,000	33,000	50	...	...
	1000	72,000	30,000	45	...	...
	1200	60,000	25,000	27	...	...
	1400	46,000	20,000	11	...	...
	1600	27,000	15,000	18	...	...
	1800	15,000	10,000	35	...	...
	2000	8,400	5,000	75	...	...
Hastelloy A......................	70	115,000	....	..	...	...
	1472	60,000	....	..	...	...
	1652	40,000	....	..	...	...
	1832	23,000	....	..	...	...

TABLE 10 CREEP DATA ON MONEL[a] AND HASTELLOY A[b]

Material	Tensile strength at atm temp, lb per sq in.	Stress to produce 0.1 % creep in 1000 hr, lb per sq in.			Stress to produce 0.01 % creep in 1000 hr, lb per sq in.			Stress to produce not more than 1 % creep per year, lb per sq in.
		600 F	800 F	1000 F	600 F	800 F	1000 F	1650 F
Monel..............	83,000	36,000	23,500	4,300	26,000	19,000	1,650	...
Hastelloy A..........	115,000	....	....	...	....	....	...	1,500

[a] "Creep Characteristics of Metals at Elevated Temperatures," by A. E. White and C. L. Clark, Transactions A.S.S.T., vol. 21, 1933, p. 11, Fig. 10.
[b] Data courtesy of Haynes Stellite Company.

TABLE 11 FORMS IN WHICH MATERIALS ARE AVAILABLE

Material	Castings	Forgings	Hot-rolled bars	Cold-drawn bars	Wire	Hot-rolled plate	Hot-rolled sheet	Hot-rolled strip	Cold-rolled sheet	Cold-rolled strip	Cold-drawn seamless tubing	Welded tubing
Nickel	x	x	x	x	x	x	x	x	x	x	x	–
Monel	x	x	x	x	x	x	x	x	x	x	x	x
H-Monel	x	–	–	–	–	–	–	–	–	–	–	–
S-Monel	x	–	–	–	–	–	–	–	–	–	–	–
K-Monel	–	x	x	x	x	–	–	–	–	x	–	–
Inconel	x	x	x	x	x	x	x	x	x	x	x	x
Hastelloy A	x to 5000 lb	x	x	–	x	x	x	–	–	–	–	x
Hastelloy C	x to 5000 lb	–	–	–	Cast welding rod	–	–	–	–	–	–	–
Hastelloy D	x to 5000 lb	–	–	–	Cast welding rod	–	–	–	–	–	–	–
Illium	x to 300 lb	–	–	–	–	–	–	–	–	–	–	–
Nickel-clad steel	–	–	–	–	–	x	x	x	x	x	x	–

x = Available.
– = Not available

ACID SALTS

Nickel possesses useful resistance to corrosion by acid salts, especially such acid chlorides as those of ammonium and zinc. Rates of corrosion in boiling concentrated solutions are of the order of 0.02 ipy.

OXIDIZING ACID SALTS

Oxidizing acid salts, as a class, are usually appreciably corrosive toward nickel, which is not recommended for use with more than extremely dilute solutions of such salts as ferric chloride, mercuric chloride, cupric chloride, and the like. Likewise, the addition of such oxidizing salts as chromates, dichromates, nitrates, and peroxides to mineral acids may make them violently corrosive to nickel.

Solutions of ferric chloride fortified with hydrochloric acid may be used for the rapid, deep-etching of nickel.

A possible exception to the rule against the use of nickel in contact with oxidizing acid salts is provided in the case of stannic chloride, dilute solutions of which nickel resists to a useful degree as compared with other strong, malleable metals. Tests in a 27.5 Bé solution at 70 F showed a rate of corrosion of nickel of only 0.018 ipy.

OXIDIZING ALKALINE SALTS

Oxidizing alkaline salts, especially hypochlorite solutions, may be very corrosive toward nickel. The upper safe limit of concentration of available chlorine is about 3 grams per liter. With this concentration nickel may be used for bleaching equipment where contact with the hypochlorite is of relatively short duration and where the metal is brought into contact with rinsing and scouring solutions after contact with the bleaching solution itself. Nickel should not be brought into contact with strong, stock hypochlorite bleach solutions, nor kept in contact with dilute bleaching solutions. When corrosion occurs it is localized in the form of pits which become filled with black and green nickel hydroxide.

A high degree of polish increases the resistance of nickel to corrosion by hypochlorite solutions. Likewise, a very small concentration of sodium silicate has been found effective in inhibiting attack by hypochlorites. As little as 0.5 cc per liter of 1.4 specific gravity sodium silicate will suffice.

Nickel is not affected by alkaline solutions containing hydrogen peroxide, such as are used for textile bleaching. Of equal importance is the fact that nickel does not accelerate the decomposition of such bleach baths.

TABLE 12 CORROSION OF NICKEL IN VARIOUS ATMOSPHERES

(From 1935 Report of Sub-Committee VI, Committee B-3, American Society for Testing Materials
Specimens were exposed for about 3 years at each test location)

Test location	Type of atmosphere	Corrosion rate, ipy[a]	Condition of specimens
Pittsburgh, Pa.	Industrial	0.0001	Uniform, green-brown, smooth film
Altoona, Pa.	Industrial	0.00011	Mottled, green-black, slightly rough film
New York, N. Y.	Industrial	0.00011	Mottled, green-gray tarnish
Rochester, N. Y.	Industrial	0.00002	Mottled, gray-black, smooth film
Sandy Hook, N. J.	Sea coast	0.00002	Slightly mottled, gray tarnish
Key West, Fla.	Sea coast	0.000004	Cold-rolled surface slightly tarnished
La Jolla, Calif.	Sea coast	0.000002	Cold-rolled surface with numerous small speckles
State College, Pa.	Rural	0.000004	Cold-rolled surface slightly tarnished
Phoenix, Ariz.	Rural	0.000001	Cold-rolled surface very slightly tarnished

[a] Inches penetration per year.

MINERAL ACIDS

Nickel is not especially resistant to corrosion by sulphuric acid, yet its behavior is good enough to enable its use in many cases. It is generally inferior to Monel and lead.

Rates of corrosion of nickel by cold sulphuric-acid solutions are less than 0.05 ipy in acid concentrations under 80 per cent by weight, even when the acid is air-saturated. In substantially air-free acid rates are less than 0.005 ipy. Maximum corrosion occurs at about 5 per cent acid concentration and decreases uniformly with increasing concentration up to about 80 per cent acid. Above this concentration, behavior is likely to be erratic, with rates of corrosion too high to make the use of nickel economical.

At temperatures near the boiling point, the highest concentration in which it is safe to use nickel appears to be about 25 per cent, and even below this concentration corrosion rates as high as 0.13 ipy may be experienced. Nickel sometimes exhibits passivity in highly concentrated sulphuric acid at elevated temperatures, but this development of passivity cannot be relied upon, and rates of corrosion as high as 5 ipy may be experienced in boiling solutions within the range of concentration from 60 to 100 per cent.

At temperatures between atmospheric and boiling, the rates

of corrosion tend to vary with concentration and temperature between 0.05 and 0.1 ipy, depending on aeration, temperature, and concentration up to 25 per cent. In concentrations above 25 per cent the use of nickel at temperatures much above atmospheric is risky.

Although as a general rule nickel is not especially useful in hot or boiling sulphuric acid of any concentration, an exception is provided by the excellent behavior of nickel tubes in evaporators or vacuum crystallizers used to concentrate the coagulating or hardening-bath solutions used in the manufacture of viscose rayon. The concentrated solutions contain about 20 per cent sulphuric acid plus sodium sulphate and other chemicals, including hydrogen sulphide. Tests on specimens exposed within an operating evaporator for 5 months yielded results shown in Table 13. It will be noted that nickel was more re-

TABLE 13 RESULTS OF TESTS IN RAYON HARDENING-BATH EVAPORATOR

(Temperature 130 F, vacuum 27 in. Hg, final sulphuric-acid concentration 20 per cent. Specimens exposed immediately above top tube sheet)

Material	Corrosion rates, ipy
Monel	0.046
Pure nickel	0.0015
Lead	0.0035
Lead galvanically coupled with nickel	0.0030
Nickel galvanically coupled with lead	0.0013

sistant to corrosion than either Monel or lead. These test results are in harmony with practical experience with nickel tubes which have replaced lead and lead-coated tubes to advantage in such evaporators.

Hydrochloric (muriatic) acid is difficult to handle with most metals and alloys, yet nickel is one of the few materials possessing useful resistance to this acid. Limiting rates of corrosion in cold acid are indicated by the curves in Fig. 1. The upper curve, as indicated, refers to air-saturated acid, and the lower curve to quiet, unaerated acid.

Nickel is ordinarily not useful in hot hydrochloric acid in concentrations greater than 1 to 2 per cent, yet in many cases it may be the most economical material to use.

In the manufacture of aniline hydrochloride, and in the chlorination of such compounds as paraffin where hydrogen chloride is present, nickel is used to a considerable extent for reaction vessels, heating coils, and agitator parts.

The resistance of nickel to corrosion by hydrochloric acid is

TABLE 14 RESULTS OF TESTS ON NICKEL IN CHLORINATED SOLVENTS

	Corrosion rates, ipy			
	Tests at 25–30 C (67–86 F)		Tests at boiling point	
Solvent	Water layer present	Water layer absent	Water layer present	Water layer absent
Carbon tetrachloride	0.00002	0.000003	0.002	0.00003
Chloroform	0.00006	0.00003	0.00012	0.0002
Ethylene dichloride	0.00001	0.000007	0.00036	0.00003
Trichlorethylene	0.0004	0.00015	0.001	0.00002
Carbon tetrachloride, Ethylene dichloride [a]	0.000003	0.000003	0.0002	0.00006

[a] Mixture containing 90 per cent by volume carbon tetrachloride and 10 per cent by volume ethylene dichloride.

responsible for its good behavior in contact with chlorinated solvents, such as are used for dry-cleaning and extraction processes. Results of tests in several of these compounds, both in the presence and in the absence of water are given in Table 14.

Nickel has limited usefulness in phosphoric-acid solutions as they are encountered in the commercial production and handling of this acid. The principal reason for this is that commercial acid often contains oxidizing compounds, such as iron salts, that accelerate the corrosion of nickel beyond reasonable limits. Pure phosphoric acid containing no oxidizing compounds corrodes nickel at rates less than 0.015 ipy in quiet exposure, and less than 0.04 ipy with aeration and agitation at atmospheric temperature. Hot, concentrated solutions cannot be handled by nickel satisfactorily.

Strong sulphurous-acid solutions are usually very corrosive

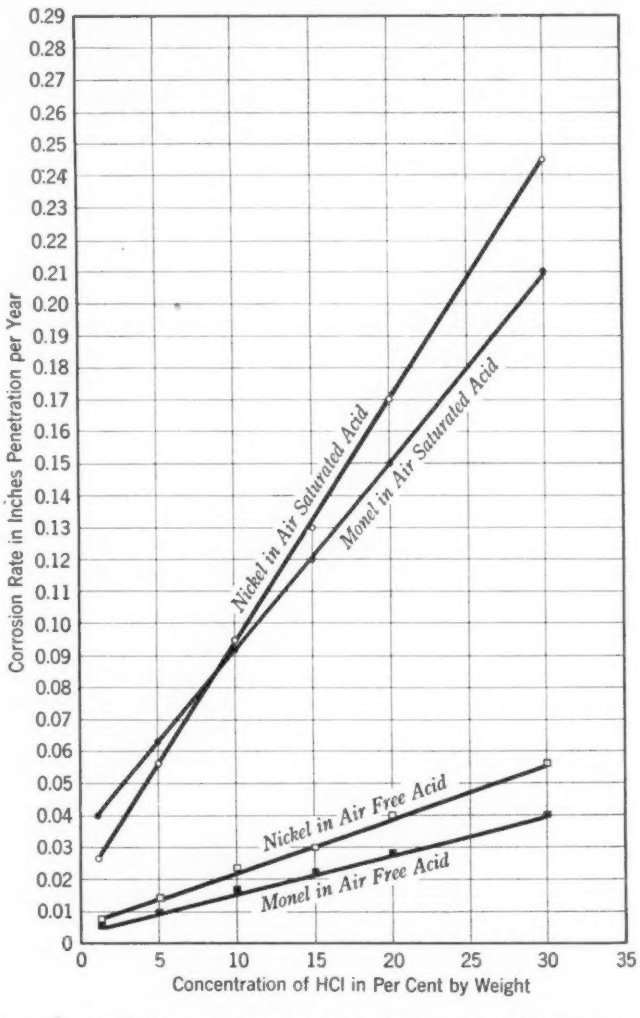


FIG. 1 RESISTANCE OF NICKEL AND MONEL TO CORROSION BY HYDROCHLORIC ACID AT ATMOSPHERIC TEMPERATURE

to nickel, especially when hot. The low concentrations of sulphur dioxide used in the preservation of food products are not destructive to nickel, although they develop a dark tarnish on the metal.

Solutions containing hydrogen sulphide are more corrosive to nickel than when hydrogen sulphide is absent, but nickel is not unique in this respect and its resistance to attack compares favorably with that of other available materials in such solutions as brines, natural waters, and alkaline solutions. Nickel oil-well strainers are used in wells where hydrogen sulphide and brine corrosion are troublesome. Samples of nickel suspended over water through which hydrogen sulphide was bubbled at 150 F were corroded at a rate of only 0.026 ipy.

OXIDIZING ACIDS

Nickel does not possess useful resistance to corrosion by oxidizing acids, such as nitric or nitrous, except in concentrations under 0.5 per cent at atmospheric temperatures. Similarly, high corrosion rates occur in other acids containing oxidizing chemicals such as ferric and cupric salts, peroxides, chromates, and the like.

ORGANIC ACIDS AND COMPOUNDS

Organic acids, under the most frequently encountered conditions, are only moderately corrosive toward nickel. At high temperatures, and when saturated with air, such acids as acetic, formic, and tartaric may be appreciably corrosive. For example, in air-saturated acetic acid at atmospheric temperature, maximum corrosion occurred with 85 per cent acid at a rate of about 0.4 ipy. In 0.1 per cent acid a rate of 0.01 ipy was observed, and in 5 per cent acid a rate of 0.04 ipy. In other concentrations the rate was from 0.04 to 0.4 ipy. In air-free acid, corrosion is considerably less, being of the order of 0.03 ipy in concentrated acid, and 0.005 ipy in quiet, dilute acid.

The behavior of nickel in boiling, unaerated acetic acid is shown by the data of Table 15. In the presence of air, nickel is likely to be corroded appreciably by hot solutions of acetic acid, and since the corrosion may take the form of pitting, the use of nickel under such conditions is not to be recommended.

Nickel possesses useful resistance to fatty acids, such as stearic and oleic, and is being used successfully for fat-splitting autoclaves. Tests in a vacuum steam still showed nickel to be corroded at a rate of only 0.004 ipy, as compared with a rate of 0.14 ipy for steel under the same conditions.

The principal commercial applications of nickel in contact with organic acids have been in connection with the handling of fruits and vegetables in which these acids occur in small concentrations. The resistance of nickel to corrosion by some typical acid foods is indicated by the data of Table 16.

While the durability of nickel food-processing equipment is, of course, important, the principal consideration determining its use in many cases is the protection from harmful contamination it affords the material being processed.

Nickel is considered to be nontoxic and numerous investigators have satisfied themselves of the safety of nickel equipment for the preparation and handling of foods. An exhaustive study of this subject was made by Drinker, Fairhall, Ray, and Drinker,[2] to whose work the reader is referred for details. Their conclusion was stated as follows: "The authors are consequently in agreement with the large group of foreign investigators who have found the preparation of food in nickel utensils is entirely safe."

It has also been found that nickel is not destructive to vitamins.[3]

Numerous investigations have established that the tolerance of food products for nickel is greater, on the whole, than for any other common metal. This is true for such products as peas, tomato juice, orange juice, wines, grape juice, beer, ale, whiskey, rum, and gin.

This lack of detrimental effects by nickel is not confined to the handling of food products, but extends into other fields. For example it has been found that certain metals are very detrimental to photographic films. Nickel does not have such an effect, and is used, therefore, to a considerable extent in the preparation of photographic-film emulsions and of gelatine for films.

[2] "The Hygienic Significance of Nickel," *Journal Industrial Hygiene*, vol. 6, 1924, pp. 307–356.

[3] "Does the Nickel Dissolved From the Container During Pasteurizing Catalyze the Destruction of the Vitamins of Milk?" A. D. Pratt, *Journal Nutrition*, vol. 3, 1930, pp. 141–155.

TABLE 15 CORROSION OF NICKEL IN ACETIC ACID BOILING UNDER REFLUX

Acid concentration, per cent by weight	Corrosion rates, ipy: Specimens in liquid	Corrosion rates, ipy: Specimens in vapors
5	0.011	0.008
50	0.019	0.015
98	0.012	0.004
99.9	0.014	0.002

TABLE 16 SUMMARY OF DATA ON RESISTANCE OF NICKEL TO CORROSION BY FRUIT AND OTHER JUICES

Material	Condition	Corrosion rates, ipy
Tomato juice	Aerated, room temperature	0.012
Tomato juice	Unaerated, room temperature	0.008
Tomato juice	Fully aerated 165 F	0.024
Tomato juice	Fully aerated 190 F	0.020
Lemon juice	Aerated, room temperature	0.020
Lemon juice	Unaerated, room temperature	0.0005
Lemon syrup	Fully aerated, room temperature	0.001
Diluted lemon syrup	Fully aerated, room temperature	0.034
Lemon juice	Boiling under reflux	0.014
Pineapple juice	Aerated, room temperature	0.018
Pineapple juice	Unaerated, room temperature	0.0035
Pineapple juice	Alternate immersion 132 to 178 F	0.010
Pineapple juice	Fully aerated 180 F	0.036
Pineapple juice	165–175 F, 16–18 in. vacuum	0.0045
Grape juice	Aerated, room temperature	0.025
Grape juice	Unaerated, room temperature	0.006
Grape juice	Boiling under reflux	0.007
Orange syrup	Fully aerated, room temperature	0.0007
Diluted orange syrup	Fully aerated, room temperature	0.025
Orange juice	Boiling under reflux	0.008
Pea brine	Boiling	0.0012
Corn brine	Boiling	0.001

In the developing of films, also, nickel is used to a considerable extent since it does not cause the "fogging" of films that may result from contamination of the developer with copper or tin.[4] While nickel is used widely in contact with developing solutions, it cannot be recommended universally for handling "hypo" or fixing solutions. In amateur work, where silver does not accumulate in the hypo to any considerable extent, nickel is satisfactory. In professional work, where silver does accumulate, the silver plates out on the nickel and tends to trap stagnant solution beneath the resulting deposits. This leads eventually to pitting of the nickel beneath the deposited silver.

In the manufacture of viscose rayon a considerable quantity of nickel is used to protect the viscose solutions from contamination by such metals as copper and iron, which are detrimental to the properties of the rayon.

Nickel in the form of nickel-clad steel is used for the construction of tank cars, for the transportation of phenol. The use of nickel protects the phenol from contamination and discoloration. Similarly, nickel is used to a considerable extent for reaction vessels in the manufacture of synthetic resins. Nickel vessels turn out a product much lighter in color and clearer than can be obtained from vessels made of other materials.

ALKALIES

Probably the most striking and useful property of nickel as a corrosion-resisting material is its practically complete resistance to corrosion by alkalies, principally caustic soda.

[4] "The Resistivity of Various Materials Towards Photographic Solutions," J. I. Crabtree and G. E. Matthews, *Industrial and Engineering Chemistry*, vol. 15, no. 7, July, 1923, pp. 666–671.

Tests in evaporators concentrating caustic soda up to 50 per cent indicate that the rate of corrosion of nickel is negligible, being of the order of 0.6 mdd or 0.0001 ipy. This good behavior is confirmed also by examination of tubes taken from service and by analyses of caustic soda for nickel. The average nickel content of 50 per cent caustic processed in nickel equipment is about 0.00005 per cent. Tubes removed from service often show no measurable decrease in thickness after several years of service, as in the case of the tube illustrated in Fig. 2. The freedom of nickel from caustic embrittlement, as indicated by the severe mechanical tests which the tube withstood, is, of course, of practical importance.

Nickel evaporators are now in service concentrating caustic soda to about 75 per cent. Rates of corrosion are slightly higher at this concentration, but available data indicate that under normal conditions the rate of corrosion is usually under 0.003 ipy, or only about 1/100 the rate of corrosion of steel.

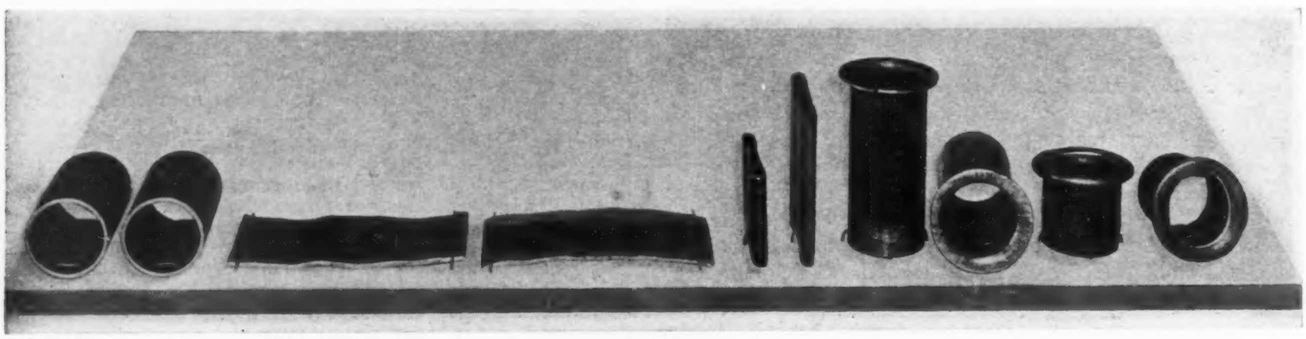


FIG. 2 NICKEL TUBE AFTER FIVE TO SEVEN YEARS OF SERVICE IN EVAPORATOR CONCENTRATING CAUSTIC SODA FROM 15 TO 50 PER CENT

In concentrations above 75 per cent caustic soda, nickel is second only to silver in resisting attack, as is indicated by the data of Table 17.

TABLE 17 TESTS ON RODS ROTATED IN CAUSTIC SODA BEING CONCENTRATED FROM 75 PER CENT TO ANHYDROUS

Metal	Corrosion rate, mdd
Silver	39
Nickel	320–440[a]
Nickel chromium (80–20)	550
Cast iron, 30 per cent nickel	680
Cast iron, 20 per cent nickel	760
Monel	1,600
Cast iron	6,660
Stainless steel (18–8 chromium nickel)	9,890
Stainless steel (18.5 per cent chromium)	15,050

[a] Five specimens of nickel, each from a different melt, were tested.

What actually determines the behavior of nickel in highly concentrated caustic soda or fused caustic is the nature of an oxide film that forms. This film is usually thin and black. In its presence the rate of corrosion by fused caustic is of the order of 20 mdd, or 0.003 ipy. Without the film, rates up to 150 mdd., or 0.025 ipy, may be expected. Temperatures above 600 F favor development of the protective oxide, whereas at lower temperatures, around 400 F, a nonprotective, green form of the oxide may develop.

The use of nickel or nickel-clad steel for caustic fusion pots in alkali plants has been prevented by the fact that the sulphur added to the molten caustic for purification would attack the nickel at a rapid rate, especially at the liquid line. On the other hand, nickel-clad steel vessels have been used successfully to hold fused, sulphur-free caustic at 1300 F and have shown no attack after eight months, where the useful life of steel was three weeks.

Nickel is not attacked by anhydrous ammonia, and is resistant to aqueous ammonia or ammonium hydroxide in concentrations under 1 per cent. Aeration may induce passivity in nickel in the lower concentrations, under 10 per cent, but in the presence of air more highly concentrated solutions are appreciably corrosive.

WET AND DRY GASES

No dry gases are actively corrosive to nickel at or near atmospheric temperatures; such gases as nitric oxides, chlorine and other halogens, sulphur dioxide and ammonia are appreciably corrosive when they are mixed with water or condensed water vapor. Nickel is resistant to chlorine and hydrogen chloride at moderate temperatures. The upper limit of usefulness is not known precisely, but is probably in the neighborhood of 250 to 300 F. At higher temperatures caution is recommended.

Nickel is free from corrosion by steam up to about 800 F. Above that temperature intercrystalline attack may occur. It is highly resistant to erosion by steam at high velocities, and is commonly used for turbine blading.

Mixtures of steam, air, and carbon dioxide are known to be corrosive to metals. In the case of nickel, experiments have shown that where the carbon-dioxide content of the noncondensable gases is less than 40 per cent by volume, corrosion will be absent or negligible. The same applies to mixtures containing more than 90 per cent carbon dioxide. In the presence of corrosion products of iron the safe carbon-dioxide limit may be reduced to about 30 per cent.

The upper temperature limit for the use of nickel in oxidizing atmospheres is, for most purposes, about 1400 F, yet it is commonly used at temperatures from 2100 to 2300 F in the form of trays and furnace bottoms for the heat-treatment of high-speed steel. At intermediate temperatures, heat-resisting alloys of the nickel-chromium or nickel-chromium-iron types are more serviceable.

Some data on the rates of oxidation of nickel and a 70 per cent nickel–30 per cent copper alloy in air are given in Fig. 3 reproduced from the work of N. B. Pilling and R. E. Bedworth.[5]

Nickel is not resistant to mixtures of nitrogen, hydrogen, and ammonia gas under conditions appropriate to ammonia synthesis. It is resistant, however, to ammonia and to nitro-

[5] "Oxidation of Copper-Nickel Alloys at High Temperature," by N. B. Pilling and R. E. Bedworth, *Industrial and Engineering Chemistry*, vol. 17, 1925, p. 372.

gen and hydrogen resulting from the "cracking" of ammonia under the conditions encountered in nitriding operations, and is used successfully for nitriding equipment. The upper useful temperature limit appears to be about 1050 to 1100 F.

Nickel is not affected by mixtures of ammonia and air encountered in ammonia-oxidation processes, and is used to a considerable extent for piping carrying the mixed gases to the converters, for connections to converters, and for devices used to support the platinum-oxidation catalysts in the converters. For the latter purpose it has been found that cast nickel containing from 3 to 3.5 per cent silicon possesses superior resistance to oxidation, as compared with the necessarily lower-silicon, wrought nickel.

Nickel is subject to attack by sulphur gases at temperatures above 600 to 700 F. Reducing conditions are worse than oxidizing, and at temperatures above about 1190 F an eutectic of nickel and nickel sulphide forms which, being molten, penetrates the grain boundaries and leads to disintegration of the metal.

In oxidizing sulphur atmospheres, e.g., sulphur dioxide, nickel suffers appreciable sulphidization up to about 1800 F, beyond which temperature the attack decreases to a considerable extent. The addition of about 4 per cent of manganese to

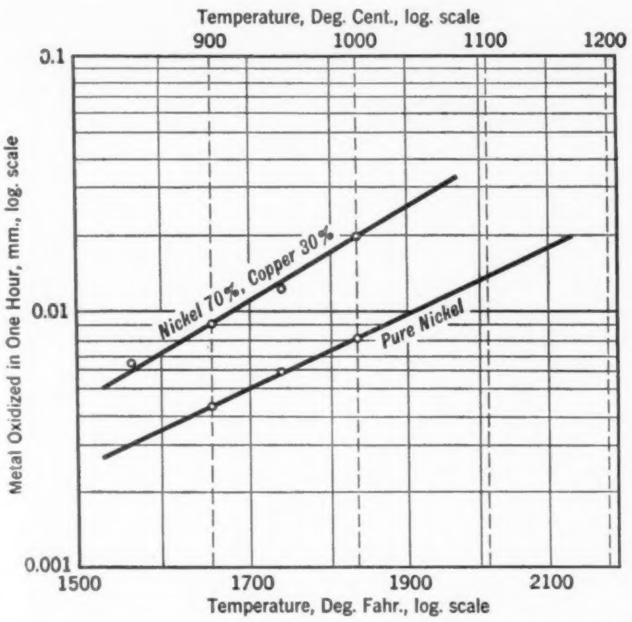


FIG. 3 OXIDATION OF NICKEL AND MONEL (70 PER CENT NICKEL) IN AIR

nickel improves its resistance to oxidizing gases containing small percentages of sulphur. This alloy is commonly used for spark-plug electrodes and for anchor bolts holding refractories, especially in marine boilers.

MOLTEN METALS

Nickel should not be used in contact with such molten metals as aluminum, tin, lead, solder, bismuth, antimony, zinc, or brass. Nickel resists amalgamation by mercury and may be used with it successfully at temperatures up to about 700 F. The metal should preferably be stress-relief-annealed as a safeguard against cracking in locally stressed areas.

CORROSION-RESISTING CHARACTERISTICS OF MONEL

Monel, which is commercially the most important of the nickel-copper alloys, is unique in that the nickel and copper of which it is composed are refined from the ore without separation. For this reason Monel has been called a natural alloy. Considerable study of the mechanical and corrosion-resisting properties of the nickel-copper series of alloys has shown Monel to possess the optimum properties of strength and corrosion resistance.

In view of the fact that both nickel and copper possess considerable resistance to chemical attack, it is not surprising that Monel should be able to withstand corrosion by many media; in fact, there is much to support the claim that Monel possesses a useful degree of resistance toward more corrosives than any other malleable metal.

Monel is benefited by the high degree of nobility of copper and by the ability of nickel to protect itself through the development of passive oxide films. Monel is more resistant than nickel under reducing conditions, and more resistant than copper under oxidizing conditions, and as a net result, it is, in general, more resistant to corrosion than either of its principal constituents.

Monel is a simple, solid-solution alloy, and is therefore free from such types of corrosion as sometimes result from local galvanic effects between phases of multiphase alloys. The closeness of nickel, copper, and Monel in the electromotive series also avoids the redeposition of dissolved copper, which appears to be responsible for the form of corrosion typified by the dezincification of high-zinc brasses.

The following notes on several types of corrosives apply particularly to regular Monel, but may be used as a general guide to the behavior of such special grades as wrought "K" Monel and cast "S" and "H" Monel. Differences among the grades are always ones of degree, and as a general rule the choice of any of the special grades should be determined by considerations of mechanical properties rather than corrosion resistance.

ATMOSPHERIC CORROSION

The ability of Monel to remain substantially unchanged—that is, free from such effects as the rusting of steel in indoor-atmospheres—combined with its resistance to corrosion by food products and cleaning solutions, accounts for its widespread use for food-service equipment in hotels, public institutions, and more recently in the home.

In outdoor atmospheres, Monel remains bright only in rural atmospheres that are essentially free from sulphur gases. In sulphurous atmospheres, such as around most cities, Monel will gradually acquire a brownish or greenish film of corrosion product at a rate which will depend on the sulphur content of the atmosphere. The effects of weathering are not unpleasing in rural, marine, and mild industrial atmospheres, and a considerable amount of Monel is used for outdoor architectural decoration. Even where the rate of tarnishing is greatest, there is no destructive corrosion of Monel. For example, the Monel roof on the Pennsylvania Terminal in New York City is still in practically perfect condition after 25 years of exposure. A section removed for examination showed no determinable decrease in gage.

Some quantitative data on the resistance of Monel to corrosion by various atmospheres were obtained in the A.S.T.M. tests previously referred to. These data are summarized in Table 18.

An important and useful property of Monel in outdoor exposure is its freedom from the development of internal structural weakness, season cracking, or stress-corrosion cracking. This, coupled with its high strength, makes Monel bolts especially valuable for electrical transmission-line hardware and for fastenings in railroad signal systems.

TABLE 18 CORROSION OF MONEL IN VARIOUS ATMOSPHERES

(From Report of Subcommittee 6, Committee B-3, American Society for Testing Materials. Specimens were exposed for about three years at each test location.)

Test location	Type of atmosphere	Corrosion rates, ipy	Condition of specimens
Pittsburgh, Pa.	Industrial	0.000029	Gray-brown, smooth film
Altoona, Pa.	Industrial	0.000036	Brown-black, slightly rough, adherent film
New York, N. Y.	Industrial	0.000043	Brown-black, smooth film
Rochester, N. Y.	Industrial	0.000006	Iridescent, dark, smooth film
Key West, Fla.	Sea coast	0.000002	Very light, green-gray tarnish
Sandy Hook, N. J.	Sea coast	0.000018	Uniform, gray-green smooth film
La Jolla, Calif.	Sea coast	0.000002	Green-gray film, spotted with corrosion product
State College, Pa.	Rural	0.000004	Very slightly tarnished
Phoenix, Ariz.	Rural	0.0000005	Very slightly tarnished

FRESH WATER

Monel possesses excellent resistance to corrosion by waters of all sorts, including distilled water and natural waters, both hard and soft. In distilled and fresh water, rates of corrosion are usually negligible, being less than 0.001 ipy and often less than 0.00001 ipy under the most severe conditions of temperature, flow, and degree of aeration. Monel is the standard material for water-meter parts, feedwater-pump parts, flush-valve parts, well strainers, etc. A growing use is for domestic hot-water storage tanks and heaters.

A spectacular use of Monel, based on its known ability to withstand corrosion and erosion by water, is for the valve seats on the 32-ft diameter gate valves which control the flow of water to the turbines at Boulder Dam.

SALT WATER

Monel has long been a sea-going metal, finding its greatest usefulness under conditions involving contact with salt water at high velocity, as in the case of propeller shafts, propellers, pump impellers, pump shafts, and condenser tubes, where resistance to the effects of cavitation and inpingement are important. High-strength K Monel is a standard material for shafts in centrifugal pumps in marine service.

Monel bolts that were installed more than 20 years ago are still in service holding together cast-iron condenser sections handling the contaminated and corrosive water of the Kill van Kull, Bayonne, N. J.

Conditions of stagnant exposure to sea water are less favorable to Monel, since marine organisms may accumulate and induce local oxygen-concentration cell action or pitting. Under such conditions, nonfouling alloys of higher copper content may be more serviceable in spite of their somewhat inferior resistance to general corrosion.

NEUTRAL AND ALKALINE SALTS

Neutral and alkaline salt solutions have a negligible corrosive action on Monel. Rates of corrosion are usually less than 0.001 ipy and seldom more than 0.005 ipy. A typical example is the widespread use of Monel in salt plants, where its resistance to corrosion by brines and wet salt is important. Tests in hot, saturated brine in a salt grainer showed a rate of corrosion of Monel of only 0.002 ipy. Tests in rotary salt driers and examinations of Monel drier linings after many years of service, indicate that the rates of thinning are 0.0015 in. per 10,000 hr of operation for steam-heated driers, and 0.010 in. per 10,000 hr of operation for oil-fired driers. The higher rate in oil-fired driers is due to the greater amount of salt handled per hour, and to the additional corrosive effect of sulphur compounds in the gases from the oil fuel. In oil-fired driers the greatest corrosion occurs in the middle third, or half way between the end of the heater tube and the feed end of the drier.

Monel is highly resistant to refrigerating brines (sodium and calcium chlorides), and is used for valves, pump parts, and ice-making machines.

Monel is practically unaffected by the solutions used in laundries for washing clothes, and is the standard material for construction of washing machines.

Similarly, in the textile industry, the resistance of Monel to the various dyeing chemicals accounts for its widespread use, especially in the dyeing and finishing of silk, cotton, and rayon.

ACID SALTS

Monel possesses useful resistance to acid-salt solutions, such as zinc chloride, ammonium sulphate, aluminum sulphate, and ammonium chloride. For example, tests in zinc chloride being concentrated from 30 per cent to 70 per cent showed a rate of corrosion of only 0.013 ipy. Monel is used successfully for coils in open zinc-chloride evaporators and for tubes in evaporators. Similarly, in an aluminum-sulphate concentrator, the observed rate of corrosion of Monel was only 0.006 ipy. Monel is used for ammonium-sulphate saturator pumps, ejectors, and centrifugal driers.

OXIDIZING ACID SALTS

Monel is not highly resistant to most oxidizing acid salts, such as ferric chloride, ferric sulphate, cupric chloride, stannic chloride, mercuric chloride, and silver nitrate. This also applies to acids containing chromates, dichromates, and other oxidizing compounds. Notable exceptions occur in connection with the dilute acid solutions containing chromates encountered in textile-dyeing processes and in the tanning industry. In connection with the latter, experience has shown Monel to be the most serviceable material for resisting corrosion by chrome tanning liquors and is used extensively for tanning-drum accessories and miscellaneous equipment. It should, however, be used with caution in contact with the highly concentrated mixtures of chromates and acids made up as stock solutions which are subsequently diluted for actual use.

Silver salts as they may occur in photographic fixing solutions are corrosive to Monel only when continued use of the "hypo" brings about sufficient accumulation of silver to cause it to plate out on the Monel. Pitting may occur under such silver deposits. In amateur photographic work, the accumulation of silver in the hypo is rarely sufficient to bring about silver deposition and pitting, and, consequently, Monel developing and fixing equipment is used extensively for amateur work.

OXIDIZING ALKALINE SALTS

Hypochlorites are the only common alkaline salts that are definitely corrosive to Monel. The limiting concentration of available chlorine that can be handled safely is 3 grams per liter. With this concentration, contact with the metal should not be continuous, and the chlorine solution should be followed by rinsing and scouring (acid) solutions, as in cyclic bleaching operations. Monel is highly useful in contact with alkaline peroxide bleaching solutions.

Monel wire cloth is a most satisfactory material for filters and cylinder molds used for the washing of paper pulp that

has been bleached with chlorine, and which often contains hydrochloric acid as well as small amounts of free chlorine.

MINERAL ACIDS

Monel demonstrates good resistance to corrosion by all acids except those of a highly oxidizing character. In non-oxidizing acids the potentials developed by Monel are rarely sufficient to cause evolution of hydrogen, and therefore, corrosion can proceed only as a result of the effect of dissolved air or other oxidizing substances in promoting the cathodic oxidation of hydrogen. Consequently, the degree of aeration of an acid solution is usually its most important single characteristic so far as corrosion of Monel is concerned.

The effects of oxygen (air) and concentration on the resistance of Monel to corrosion by sulphuric acid at atmospheric temperature, are shown in Fig. 4.

It will be noted that in air-free acid, corrosion is practically nil at all concentrations up to about 80 per cent, and that even in air-saturated acid below 80 per cent concentration, maximum corrosion at about 5 per cent concentration is equivalent to only 0.04 ipy. Experience has shown that for handling sulphuric acid below 80 per cent concentration, Monel is the most generally serviceable of the commercially available, strong, malleable materials. In acid concentrations above 80 per cent, the good behavior of ordinary iron and steel usually makes the choice of Monel uneconomical. In particular cases, such as in the handling of oil-refinery acid sludges and in the sulphonation processes where mixtures of oil and highly concentrated sulphuric acid are encountered, Monel is often the best material to use, since the oil tends to inhibit its corrosion by concentrated sulphuric acid. Tests in operating sulphonators have shown Monel to corrode at the very low rates of 0.0005 to 0.0015 ipy, and to have the additional advantage of producing a better colored product than that obtainable from iron or lead-lined equipment.

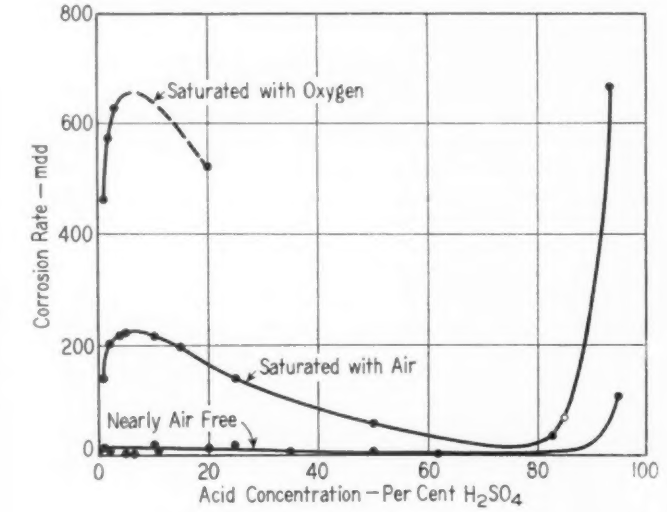


FIG. 4 EFFECT OF OXYGEN ON CORROSION OF MONEL IN SULPHURIC ACID

The effect of temperature on the behavior of Monel in 5 per cent sulphuric acid is shown in Fig. 5.

It will be noted that in air-free acid the effect of an increase in temperature is negligible, and that in air-saturated acid, the most active temperature level is about 185 F. The lower solubility of oxygen at higher temperatures probably accounts for the lower corrosion rates in the acid near its boiling point.

The excellent resistance of Monel to corrosion by the hot, dilute sulphuric-acid solutions used for pickling steel, together with its high strength and ready workability, account for what is probably the most important commercial application of Monel in resisting corrosion by sulphuric acid. The conditions of operation of pickling solutions are favorable to Monel, since while pickling is going on the solution is kept reducing by the hydrogen evolved by the steel. In addition, Monel crates, chains, and baskets are protected galvanically by the steel with which they are in contact. As a result, it is not unusual to find Monel pickling crates that are several years old which show no evidence of corrosion.

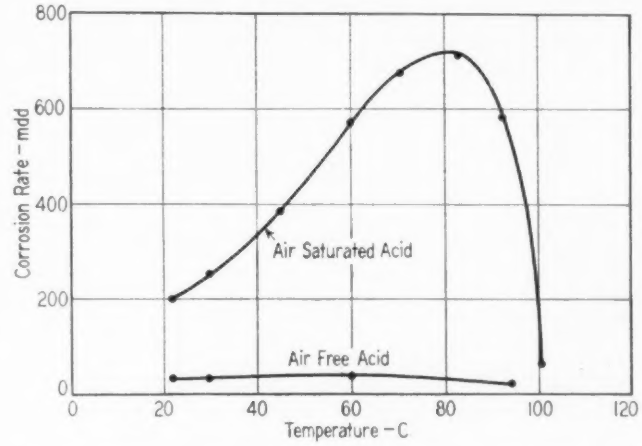


FIG. 5 EFFECT OF TEMPERATURE ON CORROSION OF MONEL IN 5 PER CENT SULPHURIC ACID

The relatively low copper content of Monel is of considerable importance in the pickling of steel for enameling, since it avoids the development of "copper flash" on the steel.

Likewise, the low copper content of Monel is advantageous in minimizing concentration cell corrosion of the rods embedded in the acid-soaked wood of pickling tanks. In the same application, the freedom of Monel from the dezincification type of corrosion suffered by brasses and aluminum bronzes is of practical importance in insuring long life and retention of strength in service.

In addition to the use of Monel for handling dilute sulphuric acid in metal-pickling processes, it is also used successfully in sulphuric-acid dye baths, wool-carbonizing equipment, leather-pickling processes, and in general where resistance to hot or cold dilute sulphuric acid is required.

Monel is one of the few metals that may be used to handle hydrochloric acid. The limiting rates of corrosion in air-saturated and air-free acid are shown in Fig. 1 from which it will be noted that air-saturated acid is from five to ten times as corrosive as air-free acid. For most purposes, the practical application of Monel is confined to contact with relatively air-free acid in concentrations under about 20 per cent by weight and at atmospheric temperature.

An increase in the temperature of the acid causes an undesirable increase in the rate of corrosion, so that in acid at temperatures in excess of about 120 F the practical application of Monel is confined ordinarily to concentrations of hydrochloric acid of less than 2 per cent by weight. At the same time, the difficulty in finding a superior, strong, malleable metal often leads to the economical choice of Monel under conditions outside the limits already noted.

Monel has been found to be the most serviceable material for parts of fruit-washing machines where dilute hydrochloric

acid at temperatures up to 120 F is used to remove poisonous insecticides, usually lead arsenate.

Monel equipment is commonly used for the pickling of steel with hydrochloric acid or mixtures of hydrochloric and sulphuric acids. Monel pickling baskets have been in use for hydrochloric-acid pickling of steel for more than 15 years.

Another application of Monel is for equipment used in glass-brightening operations, where hydrochloric acid is encountered.

The good resistance of Monel to dilute hydrochloric acid accounts for its excellent resistance to corrosion by chlorinated solvents which hydrolyze to form hydrochloric acid. Data on the resistance of Monel to corrosion by such solvents are given in Table 19. This property of Monel has led to its choice as the standard material for the construction of high-grade dry-cleaning machines and solvent distillation and reclamation units.

TABLE 19 RESISTANCE OF MONEL TO CORROSION BY CHLORINATED SOLVENTS

	Corrosion rates, ipy			
	Tests at 67–86 F		Tests at boiling pt	
	Water layer present	Water layer absent	Water layer present	Water layer absent
Carbon tetrachloride	0.0001	0.00001	0.004	0.00004
Chloroform	0.00002	0.00001	0.0045	0.00015
Ethylene dichloride	0.000025	0.00001	0.003	0.00003
Trichlorethylene	0.0007	0.00007	0.011	0.00006
Carbon tetrachloride, Ethylene dichloride [a]	0.00002	0.00001	0.001	0.00001

[a] Mixture containing 90 per cent by volume carbon tetrachloride and 10 per cent by volume ethylene dichloride.

Monel is practically unaffected by hydrofluoric acid. For example, tests in a 6 per cent hydrofluoric-acid solution used for pickling cast iron showed a rate of corrosion of Monel of only 0.0008 ipy where cast iron corroded at a rate of 7 ipy. Laboratory tests in unaerated, unagitated 48 per cent hydrofluoric acid showed rates of corrosion of Monel of only 0.004 ipy at atmospheric temperature and 0.047 ipy at 176 F.

Monel also withstands corrosion by mixtures of hydrofluoric acid and ammonium bifluoride used for the etching or frosting of glass. A typical frosting solution aerated at 130 F corroded Monel at a rate of only 0.008 ipy.

The resistance of Monel to phosphoric acid depends principally on the purity of the acid, especially in regard to the presence of such oxidizing impurities as ferric compounds. As little as 0.4 per cent ferric iron may increase corrosion tenfold. As a result, in the manufacture of the acid by treatment of phosphate salts with sulphuric acid, the inevitable presence of iron compounds limits the successful use of Monel. However, in phosphorus vaporization processes (blast or electric furnace), which yield a very pure acid, Monel is used successfully to a considerable extent, in contact with the fumes and for fans and other equipment in absorption towers.

In pure, unaerated concentrated acid at temperatures around 200 F, Monel is highly resistant to corrosion, a rate of corrosion of only 0.003 ipy having been observed in a laboratory test using 90 per cent acid at 220 F. However, at higher temperatures corrosion may be appreciable, since a test in agitated 53 per cent acid at 240 F showed a rate of corrosion of Monel of 0.5 ipy.

In cold, pure phosphoric acid without aeration, the rates of corrosion of Monel are usually less than 0.010 ipy. Corrosion is practically nonexistent in the low concentrations encountered in certain beverage syrups.

Monel is corroded at a moderate rate by hydrogen sulphide and the corrosion is accompanied by the formation of a sulphide tarnish. Tests over water through which hydrogen sulphide was bubbled at 150 F showed a rate of corrosion of Monel of 0.03 ipy. Monel resists the embrittling effect of oil-well brines containing hydrogen sulphide, and both regular and K Monels are used extensively for valve and pump parts.

OXIDIZING ACIDS

Monel possesses only a limited degree of usefulness in contact with highly oxidizing acids. In nitric acid the safe conditions of use include only concentrations under 1 per cent at temperatures not higher than 80 F, and where there is little or no relative movement between the metal and the solution.

Sulphurous acid is often very corrosive to Monel which, for example, cannot be used to handle the solutions of sulphurous acid and calcium bisulphite used to cook sulphite paper pulp. However, in dilute solutions, such as exist in spent cooking liquor or in the pulp itself, the resistance of Monel to corrosion is very good, and considerable quantities of the metal are used for pulp washers, thickeners, and screens in sulphite pulp mills.

The very dilute solutions of sulphurous acid used for the preservation of certain fruits are not seriously corrosive to Monel though they will develop a dark tarnish.

The concentrations of sulphurous acid that develop in condensed moisture from flue gases from heating equipment and smelting operations, may be appreciably corrosive to Monel. Caution should be exercised in applying Monel in flue-gas-handling systems.

In smoke-scrubbing systems, where the concentration of sulphurous acid is kept low and where an opportunity for oxidation to the less corrosive sulphuric acid is provided, Monel is often useful and is one of the few strong, malleable metals worthy of consideration for such service. Tests in operating scrubbing equipment have shown corrosion rates for Monel from 0.025 to 0.075 ipy.

ORGANIC ACIDS AND COMPOUNDS

Monel possesses useful resistance to corrosion by all the common organic acids, and is practically free from corrosion by neutral and alkaline organic compounds.

The resistance of Monel to corrosion by acetic acid, fully air-saturated and agitated, at atmospheric temperatures, is indicated by the data of Fig. 6. These data cover the most corrosive conditions at atmospheric temperature. In air-free acid, the rates of corrosion at any concentration are usually less than 0.003 ipy.

The data given in Table 20 refer to acetic acid boiling under reflux with low aeration.

Tests in stills used in purification processes involving the presence of sodium dichromate have shown rates of corrosion of Monel from 0.025 to 0.125 ipy.

Monel is highly resistant to glacial acetic acid. Tests in a condenser at 230 F showed a rate of corrosion of only 0.013 ipy.

The data of Table 21 indicate the resistance of Monel to corrosion by other organic acids.

The resistance of Monel to fruit and other food acids accounts for its widespread use in canning equipment, especially for packing, washing, and sorting tables, pipe lines, jacketed steam kettles, filling machines, and pulping equipment. Data on the resistance of Monel to corrosion by several fruit juices are given in Table 22.

Monel is resistant to corrosion by fatty acids, such as stearic and oleic, even at the elevated temperatures encountered in distillation equipment. Corrosion tests in a vacuum steam still

showed a rate of corrosion of only 0.004 ipy where steel corroded at a rate of 0.14 ipy. Monel is used successfully for bubble caps, tray supports, valves, fittings, and piping in contact with fatty acids up to 700 F.

In Twitchell process tanks the rates of corrosion of Monel have been found to be from 0.003 to 0.01 ipy.

Monel is used widely in soap plants for tops of boiling kettles, steam coils, plodder and crutcher parts, soap dies, shaving cream and tooth-paste mixers, etc.

ALKALIES

Monel is practically completely resistant to most alkaline solutions. For example, corrosion by caustic soda in concentrations up to at least 50 per cent is practically nonexistent, as

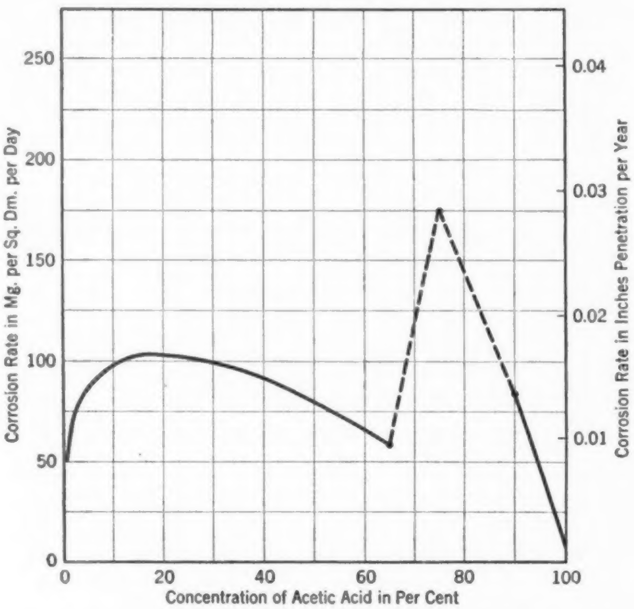


FIG. 6 RESISTANCE OF MONEL TO CORROSION BY ACETIC ACID

demonstrated both by corrosion tests and by examination of tubes removed from caustic evaporators. In a particular case, a welded Monel tube showed no measurable decrease in wall thickness after over 10 years' service in a caustic (black liquor) evaporator in a soda-process paper-pulp mill. In the same evaporator steel tubes lasted a year. The sections of tube shown in Fig. 7 were cut from a Monel tube after service of eight years in a caustic-soda evaporator producing 50 per cent caustic. The deformation which the tube withstood after exposure was conclusive evidence that no embrittlement of the metal had occurred.

Monel is resistant to anhydrous ammonia, and is commonly

TABLE 20 RESISTANCE OF MONEL TO CORROSION BY BOILING, UNAERATED ACETIC ACID

Acid concentrations, weight per cent	Corrosion rate, ipy — In vapors	Corrosion rate, ipy — In liquid
5	0.0013	0.0012
50	0.0045	0.002
98	0.0015	0.002
99.9	0.002	0.006

TABLE 21 RESISTANCE OF MONEL TO CORROSION BY UNAERATED, ORGANIC-ACID SOLUTIONS OF 30 PER CENT CONCENTRATION

Acid	Corrosion rate, ipy — Atmospheric temp	Corrosion rate, ipy — 140 F
Tartaric	0.001	0.002
Oxalic	0.0075	0.008
Citric	0.0013	0.007
Formic	0.004	0.023

TABLE 22 RESISTANCE OF MONEL TO CORROSION BY FRUIT JUICES

Product	Condition	Corrosion rate, ipy
Tomato juice	Aerated, atmospheric temperature	0.003
Tomato juice	Unaerated, atmospheric temperature	0.00002
Tomato juice	Air saturated, 165 F	0.0008
Tomato juice	Air saturated, 190 F	0.010
Lemon juice	Aerated, atmospheric temperature	0.010
Lemon juice	Unaerated, atmospheric temperature	0.0005
Lemon juice	Boiling, unaerated	0.007
Pineapple juice	Aerated, atmospheric temperature	0.005
Pineapple juice	Unaerated, atmospheric temperature	0.0007
Pineapple juice	Alternate immersion 132–178 F	0.006
Pineapple juice	Air saturated, 180 F	0.030
Pineapple juice	Boiling under 17-in. vacuum, 170 F	0.003
Grape juice	Aerated, atmospheric temperature	0.004
Grape juice	Unaerated, atmospheric temperature	0.002
Grape juice	Boiling, unaerated	0.00002
Orange juice	Boiling, unaerated	0.0008

used for equipment in which ammonia is employed as a refrigerating gas and for stems on ammonia valves.

In aqua ammonia, or ammonium hydroxide, its resistance to corrosion is good up to a concentration of ammonia (NH_3) of about 3 per cent. In higher concentrations, or in the presence of ammonium salts, corrosion is usually appreciable, being accelerated by aeration and temperature. K Monel is considerably superior to regular Monel in ammonium-hydroxide solutions, as indicated by the following test results:

RATES OF CORROSION OF REGULAR AND K MONEL IN AGITATED AMMONIUM HYDROXIDE AT ATMOSPHERIC TEMPERATURE

Concentration of NH_3, per cent	Corrosion rate, ipy — Regular Monel	Corrosion rate, ipy — K Monel
10.8	0.42	0.01
21.6	0.23	0.09

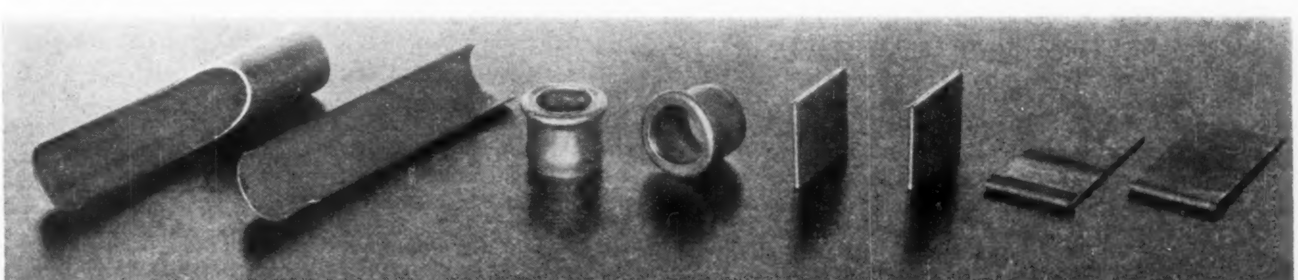


FIG. 7 MONEL TUBE AFTER EIGHT YEARS IN EVAPORATOR CONCENTRATING CAUSTIC SODA FROM 28 TO 50 PER CENT

WET AND DRY GASES

Monel is resistant to corrosion by all common dry gases at atmospheric temperature. For example, it is not affected by dry chlorine, and is the standard material for trim on chlorine-cylinder and tank-car valves and for orifice plates in pipe lines. It is also used to a considerable extent for chlorination equipment.

Monel is not resistant to such gases as chlorine, bromine, sulphur dioxide, nitric oxide, and ammonia in the presence of appreciable amounts of water or water vapor. Mixtures of carbon dioxide, air, and steam are moderately corrosive to Monel when the carbon-dioxide content of the noncondensable gases is in excess of 30 per cent by volume.

Monel is unaffected by the corrosive and erosive action of steam at temperatures up to 700 to 800 F. At higher temperatures some steam embrittlement may occur. Some applications of Monel where its high strength and resistance to steam at high temperatures are concerned, include turbine blading, valve trim, gaskets, orifice plates, etc. There has recently been developed a variety of cast Monel containing over 3 per cent silicon and known as "S" Monel, which is nongalling in rubbing contact with itself at high steam temperatures, and which is especially useful for valve trim and for steam-trap parts where service conditions are severe.

Monel is attacked by mixtures of nitrogen and hydrogen under the temperature and pressure conditions encountered in ammonia synthesis. Mixtures of air and ammonia as used in ammonia-oxidation processes, are not corrosive to Monel at moderately high temperatures, and it has been used for gas filters in connection with ammonia-oxidation equipment. For nitriding equipment, Monel is useful at temperatures up to about 1085 F provided that the manganese content of the alloy is kept below 0.5 per cent. With higher manganese content, intergranular attack occurs at the nitriding temperatures.

In reducing atmospheres containing large percentages of sulphur gases, Monel is susceptible to destructive attack at temperatures in excess of 700 F. In oxidizing atmospheres the attack is less serious and with small concentrations of sulphur gases under strongly oxidizing conditions, Monel may be used safely up to about 1000 F. However, in view of the susceptibility of Monel to sulphidization, it is desirable to avoid high-sulphur fuels for heating Monel for annealing, forging, or other hot work. The sulphur content of the fuel should be less than 0.5 per cent.

So far as resistance to oxidation in air is concerned, Monel may be used with safety without progressive scaling, up to 1000 F.

CORROSION-RESISTING CHARACTERISTICS OF INCONEL

The alloy Inconel was developed primarily to resist corrosion and tarnishing by foods, especially dairy products and fruit juices. This it does to an admirable degree. At the same time its composition is such as to make it resistant to a great variety of corrosives, and its more general use in industry is increasing rapidly. Its chromium content makes it superior to pure nickel under oxidizing conditions, while at the same time its high nickel content enables it to retain a considerable corrosion resistance under reducing conditions. In very strongly oxidizing acid solutions, Inconel is practically free from attack. However, the oxidizing effect of dissolved air alone is not sufficient to insure complete passivity and freedom from attack by air-saturated mineral acids or concentrated organic acids. The high nickel content provides excellent resistance to corrosion by alkaline solutions.

ATMOSPHERIC CORROSION

Inconel will remain bright indefinitely in indoor atmospheres and it is somewhat superior to both nickel and Monel in this respect since it avoids the "fogging" that sometimes occurs on those other materials in damp, sulphurous atmospheres.

Inconel is not completely immune to corrosion and tarnishing in sulphurous outdoor atmospheres, but compares favorably with several common alloys that are considered to possess satisfactory resistance to tarnishing outdoors. In clean country air the alloy will remain bright for many years. Free exposure to the atmosphere is more favorable to the alloy than partially sheltered exposure where the beneficial drying effects of sun and wind cannot manifest themselves.

FRESH WATER

Inconel is practically free from corrosion by distilled water and fresh water, including the most corrosive of natural waters which contain free carbon dioxide, iron compounds, chlorides, and dissolved air. It has been chosen for water-handling equipment where the most foolproof material available was desired.

SALT WATER

Inconel is highly resistant to sea water when it is in motion. In quiet or stagnant exposure pitting may occur, especially where barnacles may attach themselves to the metal surface. For this reason Inconel is rarely chosen in preference to nickel or Monel for applications involving contact with sea water. In salt-spray tests, Inconel is one of the best of commonly available materials and is worthy of consideration for applications involving exposure to marine atmospheres.

NEUTRAL AND ALKALINE SALTS

Inconel is unaffected by the majority of neutral and alkaline salt solutions. Rates of corrosion by refrigerating brines are very low (less than 0.001 ipy), and although Inconel is not entirely free from local attack, experience has shown it to be relatively free from the penetrating type of pitting that has been experienced with the iron-base chromium alloys. This property of Inconel has been especially useful in connection with equipment requiring resistance to corrosion by both food products and refrigerating brines used to cool them, as in the case of brine-cooled dairy equipment. In the design of equipment to be used with brines, no opportunity should be provided for the entrapment of liquid in crevices or between overlapping surfaces, since local corrosion may be induced at such points.

OXIDIZING ACID SALTS

Inconel is superior to nickel and Monel in its resistance to oxidizing acid salts, although this resistance does not extend to solutions containing appreciable percentages of such salts as ferric chloride, cupric chloride, or mercuric chloride. It is practically unaffected by silver-nitrate solutions and is being used extensively in contact with silver salts in the manufacture of photographic materials and for film processing equipment. Tests in used hypo fixing solutions containing silver have shown Inconel to be practically free from corrosion with an observed rate of corrosion of less than 0.000003 ipy.

Other oxidizing acid-salt solutions which it resists include chromates, dichromates, permanganates, nitrates, nitrites, copper sulphate, etc.

OXIDIZING ALKALINE SALTS

The hypochlorites are somewhat less corrosive to Inconel than to Monel or nickel, but for safety's sake it is wise to be restricted by the limitations of use set up for these other mate-

rials, as noted previously. Inconel is unaffected by alkaline solutions containing hydrogen peroxide and has no detrimental effect on the rate of decomposition of such solutions.

MINERAL ACIDS

Inconel possesses fair resistance to corrosion by sulphuric and hydrochloric acids. Its degree of resistance is not such as ordinarily to warrant its choice solely to resist corrosion by these acids, but if other reasons indicate its use its resistance to corrosion will usually be found to be adequate. In 5 per cent sulphuric acid at atmospheric temperature Inconel has been found to be corroded at a rate of about 0.125 ipy in air-saturated acid and only 0.009 ipy in air-free acid. In hot, air-saturated, 5 per cent sulphuric acid a rate of corrosion of 0.24 ipy has been observed. In the very dilute solutions encountered in the acid dyeing of wool, the rate of corrosion of Inconel has been found to be practically nil.

Tests in air-saturated 5 per cent hydrochloric acid at atmospheric temperature have shown a rate of corrosion of Inconel of 0.125 ipy. It is not recommended for use with hot or concentrated hydrochloric solutions.

Inconel is superior to most other materials in resisting hydrogen-sulphide solutions. Tests over water saturated with hydrogen sulphide at 150 F showed a rate of corrosion of only 0.01 ipy.

OXIDIZING ACIDS

Inconel is highly resistant to strongly oxidizing acids at atmospheric temperature. Corrosion by nitric acid in concentrations over 20 per cent is ordinarily less than 0.005 ipy. In dilute acid, such as 5 per cent, corrosion may be appreciable, rates over 0.2 ipy having been observed.

Nitrous-acid solutions such as are encountered in diazotizing baths used in the application of developed color dyes are not at all corrosive to Inconel.

The resistance of Inconel to oxidizing acid solutions extends to mixtures of mineral acids with such oxidizing salts as chromates and permanganates encountered in the textile and tanning industries and in photography, and to copper sulphate and small concentrations of ferric sulphate such as are found in acid mine waters. Rates of corrosion are usually less than 0.005 ipy. Inconel is not resistant to solutions containing appreciable percentages of sulphur dioxide, although it is superior to both Monel and nickel in resisting tarnishing by the dilute solutions encountered in food processing.

ORGANIC ACIDS AND COMPOUNDS

One of the most useful properties of Inconel is its practically complete resistance to corrosion by organic acids as they occur in food products, including fruit juices and alcoholic beverages. Rates of corrosion by these products are ordinarily less than 0.002 ipy. Cooking tests with some 30 different foodstuffs known to be especially corrosive to metals showed no visible tarnishing or other evidence of corrosion.

The resistance of Inconel to hot, concentrated organic acids, such as acetic and formic, is fair, but not sufficiently outstanding to warrant the choice of Inconel over other available materials. An exception is provided in the case of mixed fatty acids, stearic and oleic, to which Inconel is practically completely resistant. A rate of corrosion of less than 0.0001 ipy was observed in a test in a vacuum steam still at 600 F.

ALKALIES

Because of its high nickel content, Inconel is practically free from corrosion by alkaline solutions; for example, tests in 70 per cent caustic soda at 260 F showed a rate of corrosion of only 0.00004 ipy. However, in very highly concentrated caustic, such as 90 per cent caustic at 800 F, the chromium content of Inconel makes it subject to rapid corrosion.

Inconel is especially useful in resisting corrosion by alkaline sulphur compounds, for example tests in 50 per cent sodium sulphide at 340 F showed a rate of corrosion of Inconel of only 0.004 ipy. Inconel is being used successfully for handling the alkaline sulphur solutions encountered in the manufacture of sulphate or Kraft paper, and in viscose rayon desulphurizing operations.

WET AND DRY GASES

Inconel is not affected by any dry gas at atmospheric temperatures. It is not resistant to wet chlorine, bromine, or sulphur dioxide. It is completely resistant to all mixtures of steam, air, and carbon dioxide and is especially useful in contact with steam at high temperatures in excess of 800 F. Experience has shown Inconel valve trim to be especially useful under severe service conditions where other materials suffer from wire-drawing effects. Inconel springs function properly in steam at temperatures up to 800 F.

Inconel resists progressive oxidation at temperatures up to 2000 F, and an important use is for the sheathing of electric heating elements. Specimens of welded tubing used for sheathing have withstood alternate heating to 1625 F and cooling to room temperature for a period of 5000 hr without any deterioration. In oxidizing sulphur atmospheres, e.g., sulphur dioxide, the safe operating-temperature limit is about 1500 F and in reducing sulphur atmospheres, e.g., hydrogen sulphide, the safe upper limit is about 1000 F. Tests in the intermediate tower of a cracking unit handling high-sulphur oil at 670 F showed a rate of corrosion of Inconel of only 0.0004 ipy.

A useful property of Inconel for high-temperature service is its resistance to deterioration and embrittlement in the critical-temperature range from 1000 to 1400 F. For this reason it is being used to a considerable extent in the fabrication of exhaust systems and cabin heaters on aircraft engines.

Inconel is resistant to ammonia, nitrogen, and hydrogen as they are encountered in nitriding operations. Tests have shown a rate of attack by the nitriding gases of only 0.00035 in. per 100 hr of operation.

CORROSION-RESISTING CHARACTERISTICS OF THE HASTELLOY ALLOYS

Hastelloy A was developed primarily as a material to resist corrosion by hydrochloric acid and the extent to which it does this is its most important property.

Hastelloy C possesses an unusual degree of resistance to oxidizing solutions, especially those containing chlorides, in addition to other corrosive chemicals. It is unique among alloys in its resistance to corrosion by hypochlorite solutions and moist chlorine.

The most important property of Hastelloy D is its resistance to corrosion by concentrated solutions of sulphuric acid at elevated temperatures.

All of these materials are practically free from corrosion under such relatively mild conditions as exposure to the atmosphere, fresh and salt water, and neutral and alkaline salts. Therefore, these will not be discussed in any detail.

MINERAL ACIDS

Hastelloy D is resistant to all concentrations of sulphuric acid at temperatures up to the boiling point. For example, tests in 55 per cent acid evaporated to fumes indicated a rate of corrosion of Hastelloy D of only about 0.05 ipy. Hastelloy D

has been used successfully for equipment employed in the concentration of sulphuric acid by evaporation.

Hastelloy A is usefully resistant to sulphuric acid in concentration up to 50 per cent at the boiling point and in concentrations over 50 per cent up to 160 F. For example, tests in boiling 25 per cent acid have shown a rate of corrosion of 0.05 ipy and in boiling 60 per cent acid a rate of about 0.5 ipy. At atmospheric temperatures rates are ordinarily less than 0.01 ipy in concentration up to at least 96 per cent.

Hastelloy C is generally superior to Hastelloy A in its resistance to sulphuric acid, although the same limitations apply to its use, that is, boiling acid only up to 50 per cent concentration, and up to 160 F in acid concentrations from 50 to 100 per cent.

Hastelloy A is resistant to all concentrations of hydrochloric acid at temperatures up to 160 F. Rates of corrosion are usually less than 0.03 ipy at the upper useful limit (160 F) and appreciably less at lower temperature. Aeration tends to increase corrosion, especially in dilute acid where maximum attack occurs in about 2 per cent acid, but even in air-saturated acid the maximum rate of corrosion at atmospheric temperature is only 0.040 ipy and Hastelloy A is superior to all other commercially available malleable materials.

Hastelloy C is resistant to all concentrations of hydrochloric acid at atmospheric temperature and may be used successfully up to 160 F. However, near the limiting temperature Hastelloy C is only about one quarter as resistant as Hastelloy A, which is, therefore, the better choice of material for elevated temperature.

Hastelloy D also possesses a useful resistance to hydrochloric acid, although it is inferior to both Hastelloys A and C, and the highest temperature for which it is recommended is about 110 F.

Hastelloy A is not recommended for use with phosphoric acid, but the other alloys, Hastelloy C and Hastelloy D, are highly resistant to attack and are especially useful where the acid is not pure and contains fluorides or oxidizing impurities. At very high temperatures, e.g., 300 F, Hastelloy D is superior to Hastelloy C. Hastelloy D is considerably more resistant to concentrated crude acid than to dilute crude acid and should be used with caution with the latter.

None of these materials is especially resistant to hydrofluoric acid; Hastelloy A is not recommended, while Hastelloy C and D may be used in concentrated acid at atmospheric temperatures.

Hastelloy C posssesses useful resistance to hot and cold sulphurous-acid solutions and is especially valuable where the solutions contain both sulphuric and sulphurous acids. Hastelloy A and Hastelloy D are not resistant to sulphurous-acid solutions.

Hastelloy C is highly resistant to hydrogen sulphide and to solutions containing this gas.

OXIDIZING ACIDS

Hastelloy C is resistant to dilute nitric acid at temperatures up to about 150 F and to acid over 40 per cent concentration only at atmospheric temperature. In 20 per cent acid at 160 F a rate of corrosion of about 0.05 ipy was observed. In 70 per cent acid at atmospheric temperature the rate of corrosion was 0.005 ipy and in 10 per cent acid 0.015 ipy.

Hastelloy A and D are not resistant to nitric or other strongly oxidizing acids in any appreciable concentration.

As would be expected, Hastelloy C is highly resistant to oxidizing-acid mixtures such as nitric and sulphuric, chromic and sulphuric, sulphuric and copper sulphate, sulphuric and dichromates, permanganates, persulphates, etc.

ORGANIC ACIDS

All of these materials are highly resistant to organic acids, but are rarely chosen for this property alone, since lower-cost materials which possess adequate resistance are readily available.

ACID SALTS

Hastelloy A and C are highly resistant to acid chloride salts, such as ammonium and zinc chlorides. Hastelloy C and Hastelloy D resist acid sulphates such as aluminum and ammonium sulphates, and acid phosphates.

OXIDIZING ACID SALTS

Hastelloy C possesses an unusually high degree of resistance to such highly corrosive chemicals as ferric chloride and ferric sulphate, and mixtures of oxidizing salts such as chromates and nitrates with sulphuric and hydrochloric acids. In the presence of hydrochloric acid or chlorides Hastelloy C gives superior service. Cupric chloride is probably the most corrosive chemical likely to be encountered and even Hastelloy C must be used with caution with this chemical, even at atmospheric temperature. With other oxidizing acid salts care should be exercised at temperatures above about 160 F.

OXIDIZING ALKALINE SALTS

Hastelloy C is the only material possessing resistance to hypochlorites and other solutions containing free chlorine in appreciable concentrations. Even Hastelloy C may be attacked in strong solutions at temperatures much above atmospheric and caution should be exercised at temperatures over from 70 to 80 F.

WET AND DRY GASES

Hastelloys A and D are resistant to progressive atmospheric oxidation and to both oxidizing and reducing flue gases and to carbon monoxide, carbon dioxide, and hydrocarbons at temperatures up to about 1500 F. Hastelloy C is resistant at somewhat higher temperatures, the upper limit being about 1800 F.

All the Hastelloys are resistant to ammonia.

Hastelloys C and D are highly resistant to hydrogen sulphide and sulphur dioxide up to about 160 F. With sulphur trioxide, Hastelloy C is useful only up to 160 F. Hastelloy A is not recommended for use with any of the sulphur gases.

Hastelloy C is the only alloy of this group resistant to wet chlorine and may be used at temperatures up to about 90 F. At higher temperatures local attack may occur.

CORROSION-RESISTING CHARACTERISTICS OF ILLIUM

Illium was the result of a search for a material resistant to both sulphuric and nitric acids over a wide range of concentration and exposure conditions. It is superior in applications under highly oxidizing conditions, such as nitric acid, and has limited applications in hydrochloric acid and acid chlorides.

This material is practically free from corrosion under such relatively mild conditions as exposure to the atmosphere, fresh and salt water, and neutral and alkaline salts. Therefore these will not be discussed in any detail.

MINERAL ACIDS

Illium is usefully resistant to sulphuric acid under all conditions of concentration, aeration, agitation, and temperature. Tests in boiling 25 per cent sulphuric acid have indicated a rate of corrosion of only 0.01 ipy. Illium has been found to be

especially useful for parts of pumps and other equipment handling chamber process sulphuric acid containing oxidizing nitrogen compounds present in the chamber process. It is also highly resistant to the complex sulphuric-acid solutions which are used as coagulating media in the manufacture of viscose rayon.

Illium is resistant to hydrochloric acid up to about 15 per cent concentration at atmospheric temperature, but is not recommended for use with more concentrated acid or with hot dilute acid. It is highly resistant to attack by phosphoric acid and is especially useful where the acid is not pure and contains fluorides or oxidizing impurities. It is not especially resistant to hydrofluoric acid, but possesses useful resistance to sulphurous-acid solutions, especially where both sulphuric and sulphurous acids are present, and is highly resistant to hydrogen sulphide and to solutions containing this gas

OXIDIZING ACIDS

Illium is resistant to all concentrations of nitric acid at all temperatures. Tests in boiling 25 per cent acid showed a rate of corrosion of only 0.01 ipy and in cold 70 per cent acid the rate was less than 0.001 ipy.

Illium is highly resistant to oxidizing-acid mixtures such as nitric and sulphuric, chromic and sulphuric, sulphuric and copper sulphate, sulphuric and dichromates, permanganates, persulphates, etc.

ORGANIC ACIDS

Illium is highly resistant to organic acids but due to the availability of lower-cost materials possessing adequate resistance it is rarely chosen for this property alone.

ACID SALTS

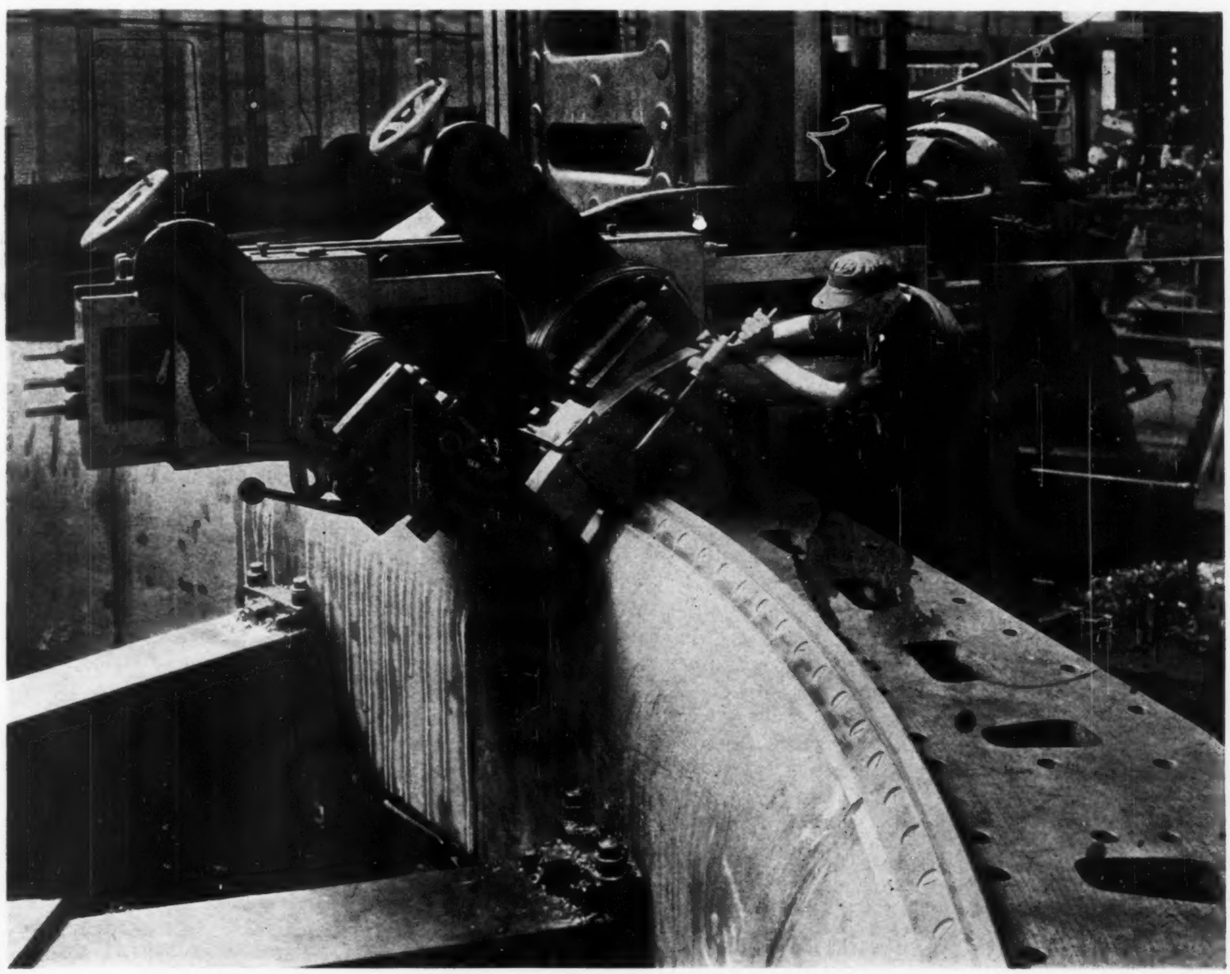
Illium resists acid sulphates, such as aluminum and ammonium sulphates, and acid phosphates.

OXIDIZING ACID SALTS

Illium possesses a high degree of resistance to such highly corrosive chemicals as ferric chlorides and ferric sulphate, and mixtures of oxidizing salts such as chromates and nitrates with sulphuric and hydrochloric acids.

It is obviously impossible to cover in general notes such as have been presented all the variables of solution composition, concentration, and temperature that may be associated with corrosion problems. For detailed information on specific applications the reader should communicate with the producers of the alloys discussed, using these notes only as a preliminary guide in the choice of a material for a particular purpose.

NOTE: Because of space limitations, a section of Mr. LaQue's paper dealing with working instructions for Monel, nickel, and Inconel, has been omitted. It will appear in a later issue.—EDITOR.



FINISHING THE MONEL SEAT OF ONE OF THE GIANT 32-FOOT INTAKE GATES FOR BOULDER DAM

FOREIGN POLITICAL SYSTEMS

By ALBERT A. SCHAEFER

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

THE dictionary informs us that locusts are leaping orthopterous insects of the family Acrididae who often travel in vast swarms, destroying the vegetation of the places they visit. The males (sometimes also the females) usually possess stridulating organs by which they emit shrill creaking noises. In the Eastern countries some species are eaten. Traditionally the most devastating swarms appear each seventeenth year. In this respect locusts differ from politicians who, in the United States, swarm in vast numbers each fourth year. Also, they are inedible.

Every leap year the American air is charged and surcharged with raucous voices uttering unintelligible noises. In the press and on the platform the dear and patient "peepul" are advised that unless the policies advocated and espoused by the particular paper or person are not speedily adopted the nation is doomed to eternal damnation. Solemnly they are warned that there are storm clouds upon the horizon, as yet no larger than a man's hand, which portend the coming storm. That such dire prophecies seldom eventualize has no deterrent effect. The assumption of omniscience is the distinguishing characteristic of the office-seeker. And in no branch of learning is this assumption more abused than in the discussion of the various types of government now functioning on the continent of Europe.

The campaign of 1936 was no exception. Nightly, speakers arrogantly assumed to educate their listeners in regard to the several systems of government operating in European countries. Naturally the avowed intent was to disparage these systems that the "American way" might shine by comparison. Untruths and half-truths tumbled over each other in rapid succession. And this is the more distressing since it is obviously so unnecessary. It can arise only from ignorance. A calm dispassionate consideration of certain of the European systems will disclose that neither in theory nor in fact are they adaptable to American conditions. For this reason the publishers who are sponsoring the series of monographs upon the five governments of modern Europe are to be congratulated not only upon their initiative and foresight but more especially upon the admirable results obtained in their first two publications, "The Fascist Government of Italy,"[1] by Prof. Herbert W. Schneider, of Columbia University, and "The Government of Switzerland,"[2] by Prof. William E. Rappard, of the University of Geneva in Switzerland.

Professor Schneider is admirably fitted to discuss how fascism works in Italy today. Professor of Religion at Columbia University, he has found time to study in detail and at first hand the fascist state. His two earlier books on Italy, "The Making of the Fascist State," and "Making Fascists" (written in collaboration with S. B. Clough), have commanded wide respect from students of political science. His recent work, "The Fascist Government of Italy," published in the spring of 1936, is perhaps not so profound but equally well designed to accomplish the objects sought thereby. It is, says Professor Schneider, "intended primarily for the use of young students, who approach political science with innocent enthusiasm and deference." It is "not a book about fascism nor about Italy" but "it is confined to the description of how fascism is working in Italy at present." Herein lies its strength. Too often writers or political institutions adopt the theoretical approach, disregarding entirely the actual workings of the system which frequently are widely at variance with theory. In our own country one needs only to consider the present development of the party system and the rubber-stamp functions of the electoral college to sense that theory and fact do not always coincide. Actualities rather than potentialities should be the primary elements in any objective scientific study.

It is, therefore, refreshing to have so authoritative a writer as Professor Schneider, at the very outset, caution his readers that the current belief "that the totalitarian state implies that the government rules everything" is far from the truth. Nor is a dictator as arbitrarily supreme as some would believe. He must "be popular and can govern only because he knows how to be governed." The postwar dictatorships differ radically and fundamentally from the prewar autocracies. In the old-fashioned systems the masses of the people were rigorously excluded from participation in the affairs of state. Coercion not cooperation was the directing force. In the modern dictatorships there is at least an attempt to obtain the support of the masses, although it must be conceded that there is a very definite and controlled propaganda by which this support is emotionally rather than intellectually obtained. Here it is to be regretted that Professor Schneider has not elaborated more as to the part which the Fascist party plays and will play in the performance of this function.

The book is factual but not statistical. It deals in reasonable but not too great detail with the geographical, historical, ethnological, and economic background of the Italian people. It neither commends nor condemns the resultant form of government. To quote from the preface: "it contains, however, the elementary information required to estimate the extent to which fascism has worked a revolution in Italian politics." Professor Schneider briefly comments on the effects of the fascistic régime upon Italian culture, but does not press conclusions. The reader is left to form his own judgment on the fascistic theory as it is working out in action. Hence it stimulates rather than directs thought. There is also a brief discussion of the Italian foreign and colonial policy.

Appended are eight pages of bibliographical references to the chief source materials for the recent history of Italian government. Most of these are to Italian publications for which there are but few available English translations. A word of caution with respect to these materials may not be amiss. The eager student unfortunately cannot always distinguish fact from propaganda. And many of these articles are the product of persons frankly interested in the continuance of Mussolini's policies. However, this by no means detracts from the general excellence of the book. It should

[1] "The Governments of Modern Europe, D. Van Nostrand Company, Inc., New York, 173 pp., 1936, $1.25.

[2] "The Governments of Modern Europe, D. Van Nostrand Company, Inc., New York, 153 pp., 1936, $1.25.

One of a series of reviews of current economic literature affecting engineering prepared by members of the department of economics and social science, Massachusetts Institute of Technology, at the request of the Management Division of The American Society of Mechanical Engineers.

be read by all interested in the present developments of the fascistic idea, especially by those who are emotionally opposed without proper factual knowledge to form a rational conclusion.

The second in the series of monographs dealing with the governments of modern Europe is "The Government of Switzerland," by Prof. William E. Rappard, of the University of Geneva, published in the fall of 1936. Here we have an authoritative exposition of the government of Switzerland by a local resident. It is perhaps less factual than Professor Schneider's work on Italy and more interpretative. Because of the close similarity of many of the institutions of Switzerland and the United States, Dr. Rappard's book should be of great interest to the American readers. As Dr. Rappard points out, "It is natural that the dualism thus created of state and cantonal government, on the one hand, and federal government on the other, should have led the American and Swiss nations constantly to compare notes on their respective experiences."

Internally the ethnological backgrounds of the two countries have much in common. Each has a composite population made up of many varying racial groups. This has had a profound effect in each nation upon problems of foreign relations and policies of neutrality. Divergent national sympathies of expatriates are influential factors. Although geographically the problem of isolation is less acute in the United States than in Switzerland, "A pygmy state surrounded by gigantic neighbors," yet the method of treatment of the problem is not without interest to our own country. Dr. Rappard adequately portrays the problem and its successful handling over centuries of time.

But it is in his study of the actual working of the federated system that Dr. Rappard contributes most to the American student. In these days, when many writers assert that duality of sovereignty within a single territorial area is unworkable and leads to constant conflicts, it is of more than passing interest to know how Switzerland carries on. In the chapter on the federal executive and the federal judiciary a clear picture is presented of the actual workings of the Swiss system, with ample comparisons with the American system.

The rise of the political parties is briefly but sufficiently sketched. Dr. Rappard points out that these parties have more a local than a federal existence. Thus "there is a great diversity both of principle and of practice in cantonal parties bearing the same name and belonging to the same national groups." Hence "a complete study of party politics in Switzerland would therefore have to be based on a series of cantonal monographs." Dr. Rappard does not, for obvious reasons, attempt this. But he does show that with one exception there are no autonomous national parties in Switzerland similar to those existent in the United States. "There are no nation-wide elections in which all the citizens of the country are urged to vote for or against the same candidate to a national office and on which they are thus called to choose the Government of the day and thereby to allocate the patronage which goes with such choice." This is the major contrast between Swiss and American politics.

As in the case of Professor Schneider's book on the fascist government, so also Dr. Rappard has attempted merely to give an elementary view of the government of Switzerland. Considering the limitations of space—the book is but 150 pages—he has succeeded admirably in attaining his object. His specialized knowledge of the people, their national life and characteristics is apparent in the breadth and conciseness of his treatment. It is a work well worthwhile and should be read with interest and instructiveness by all American students.

We shall await with interest the three remaining volumes in the series, now in preparation: "The Government of the French Republic," by Prof. Walter R. Sharp, of the University of Wisconsin; "The Nazi Government of Germany," by Prof. James K. Pollock, of the University of Michigan; and "The Government of the Soviet Union," by Prof. Samuel N. Harper, of the University of Chicago.

Cast Iron in Chemical Equipment

(*Continued from page 808*)

100-hr intervals under the conditions of the furnace atmosphere as follows:

(1) Furnace contents protected from outside air.
(2) Dry air aspirated through the furnace at the rate of 2 liters per hour.
(3) Air saturated with water vapor and aspirated through the furnace at the rate of 2 liters per hour.
(4) Illuminating gas aspirated through the furnace at the rate of 2 liters per hour.

The results are shown in Tables 2 and 3.

TABLE 2 EXPERIMENTS AT 750 C—100-HR EACH

	Gain or loss in weight, per cent			
Alloy	1	2	3	4
Cast iron, no alloy added	+3.21	+1.51	+1.36	+0.03
Chrome-nickel cast iron	+2.45	+1.82	+1.17	−0.02
Ni-resist	−0.31	+0.44	+0.54	+0.02

TABLE 3 EXPERIMENTS AT 950 C—100-HR EACH

	Gain or loss in weight, per cent			
Alloy	1	2	3	4
Cast iron, no alloy added	−6.89	−9.45	−12.26	−14.43
Chrome-nickel cast iron	−0.79	−4.27	−7.63	−7.58
Ni-resist	+1.93	+3.89	−1.90	+2.64

Ni-resist developed and maintained a thin, dark, adherent scale at both 750 and 950 C during the 100 hours of the experimental runs. The moist air used in the tests at 950 C appeared to loosen the scale to the extent that there was a slight loss of weight. It is felt that the summary of results from these tests will suggest additional applications for these materials in a more concise manner than otherwise possible.

Heat Transfer in Evaporation and Condensation—II

IN Dr. Jacob's fifth lecture on this subject which was published in the November issue, the following correction should be made on page ~~533~~. 733

Under the heading "2—Some Results of Experiments on Film Condensation," the first paragraph should read as follows:

"I am compelled to restrict myself to only a few of our latest results. Figs. 6 and 7, embracing the results of 171 experiments, represent the density of the heat flow q_D in kcal per sq m per hr as a function of $\vartheta_s - \vartheta_{Rm}$, ϑ_s being the saturation temperature and ϑ_{Rm} the mean temperature of the inner surface of the tube. In transforming the values shown on these diagrams from the German to the English units, values of q_D should be multiplied by 0.368, in order to obtain q_D in Btu per sq ft per hr and later on those of the coefficient of heat transfer α by 0.205, in order to obtain α in Btu per sq ft per hr per deg F. The temperatures of our experiments refer to only two values, 212 F as the saturation temperature and 617 F as the entrance temperature of superheated steam.

ENGINEERING PROGRESS

A Review of Attainment in Mechanical Engineering and Related Fields

BECAUSE the editor of this section, who has abstracted the articles that have appeared in it since the establishment, in 1912, of the "Foreign Review" as it was then called, is on leave of absence, space devoted to the abstracts has been reduced.—EDITOR.

AERONAUTICS

Direct-Take-Off Autogiro

AUTOGIROS have been developed which are capable of rising vertically from the ground without any forward run and of descending in a similar manner. Two such machines were demonstrated in England in July, 1936. The necessity of a short run on the ground at take-off and landing has been obviated by making use of the inertia of the rotor to give the initial vertical lift. A new type of two-bladed rotor has been developed and is said to be inherently stable under all conditions. The pitch of the blades is automatically variable.

When taking off, the rotor is driven from the engine through the inclined shaft with universal joints, the upper end of the shaft being fitted with a bevel pinion which engages with a crown wheel on the rotor hub, and the lower end being connected to the engine through a clutch. When this clutch is engaged the rotor is turned and the speed is gradually increased until the rotor is running at a considerably higher speed than is required for normal flight. The pitch of the rotor blades is then such as to give no lift with a minimum drag. When the clutch is disengaged, however, the blades automatically turn to the high-lift position, and as the rotor continues to rotate by its own momentum the lift produced is sufficient to overcome the weight of the machine, which rises to a height of some 20 or 30 ft, after which normal flight is commenced. During flight the rotor is driven by the relative wind, only the airscrew being driven by the engine. The speed of the rotor blades in flight is independent of the forward speed of the machine and remains practically constant from the maximum speed in horizontal flight to zero forward speed, i.e., vertical descent. In descending, as soon as the machine touches the ground a brake is applied to the rotor, which turns the blades to the no-lift position and reduces the lift to zero. This prevents the machine from overturning after landing and is especially useful in gusty weather conditions. The characteristic of direct take-off and vertical descent obtained in these machines would obviously enable them to rise from or descend on to any field, or other small open space, and to clear such obstructions as bushes or small trees. (*Engineering*, vol. 142, no. 3681, July 31, 1936, p. 129)

The Orthoplane

THE orthoplane means an airplane adapted to fly straight up from rest in still air. Many planes having their control surfaces in propeller streams have been patented and some flown, at least in model form.

The author warns against assuming that orthoplanes can hover in still air with a weight exceeding the propeller thrust. On the other hand, the author shows in diagrammatic form (Fig. 1 in the original article) an orthoplane having its ailerons in slipstreams and its thrust exceeding the gross weight.

The author proves certain theorems dealing with orthoplane operation, beginning with a statement that the weight dynamically supported by an airplane equals the rate of downward momentum it imparts to the air. The first theorem to be proved is that a hovering airplane cannot exert a dynamic lift exceeding its propeller thrust. The purpose of throwing the slipstream against fixed wings, though no gain of lift ensue, is mainly to let the craft hover more nearly horizontal or fly more slowly. The truth is that an orthoplane can hover without wings when pointed upward, supported by its screws, and poised by its tail unit. This unit can be fashioned to exert three-moment control; e.g., by making the flippers turn at will oppositely or identically while the rudder works as usual. Such an airplane, however, is but a freak helicopter.

Orthoplane wings are needed not for vertical but for horizontal flying. They may be of a large or of a small type. Large wings are useful for slow flight or dead-stick landings. A very swift orthoplane can be made with narrow fin-like wings for holding ailerons but too small for dead-stick landings. It could land like a helicopter supported by its screws. A racer of this type could fly vertically at fair speed, and horizontally at over more than 500 mph.

The formulas assume untrammeled flow. With external flow baffles the lift of an air-borne craft may exceed the propeller thrust. For instance a flatboat with side and end flanges dipping in the water can float on air supplied by a propeller whose thrust is indefinitely small.

The author proceeds next to establish the point that no airplane can take off vertically from rest unless endowed with a thrust equal to its weight, but if so endowed it may fly along a slope with surplus thrust available for acceleration or speed. He proceeds to prove that in steady flight with a given thrust and a given incidence, the wing lifts substantially the same when wholly in the propeller wash or when wholly outside.

The author arrives at the conclusion that an orthoplane can be made to fly at any speed from zero to well beyond the highest yet attained by any racing plane. As to design he states that the control surface should be so placed as to remain constantly in the wash.

The ailerons can be of full wing length; the wing span can be much reduced in speed types. (A. F. Zahm, *Journal of the Aeronautical Sciences*, vol. 3, no. 9, July, 1936, pp. 329–330)

FUELS AND FIRING

New Type of Heating Elements

THE Wild-Barfield Electric Furnaces Ltd., London, England, has developed a new type of heating element for electric furnaces, designated "tubular-hairpins."

These new elements consist of nickel-chromium tubes joined at one end by a solid rod connector, and having thickened ends of nickel chromium at the other extremities where the leadouts pass through the insulation, with mild-steel

screwed ends for connecting purposes.

The particular use for this element is for furnaces employing temperatures up to 2100 F. The main advantages claimed are that there is no inner core, consequently the maximum element temperature is low; also, a tube is extremely rigid and there is therefore little sagging at elevated temperature. (*Heat Treating and Forging*, vol. 22, no. 8, August, 1936, p. 404, 1 fig.)

Underground Gasification of Coal

THE possibilities of underground gasification of coal on a commercial scale formed the basis of a paper read before the recent Chemical Engineering Congress of the World Power Conference by P. A. Chekin, A. I. Semenoff, and J. S. Galinker. The paper was based on experiments carried out in Russia since 1917. The basic idea is that it may pay to convert coal into gas, particularly water gas, in situ, without trying to separate the coal from the roof and take it to the surface. The details of the mechanics of the early tests are described in the original article. Among other things a blow enriched with oxygen has been used.

The roofing breaks down as the coal burns out and the channel increases; owing to the steep dip of the coal bed, pieces of rock accumulate at the bottom and do not cover up the burning bed. Accordingly, just at the burning surface, there still remains a free channel, through which the gases pass. The width of this channel depends solely on the soundness of the roofing, which must resist the rock pressure. As the channel becomes wider, the durability of the arch gradually decreases, and on reaching a certain limit it breaks down. This has a favorable effect upon the process, because, notwithstanding the burning out of the coal, the construction of the generator is not changed. The foregoing method was named gasification by the "stream" method.

The process went on smoothly and the composition of the gas was so steady that the proportion of the basic components in it scarcely underwent any change in the course of 24 hr. It should be pointed out that such a steady output is rarely observed even in gas producers operating above ground. Any desirable alteration in the quantity of gas or in its composition was easily obtained by changing the quantity or composition of the blow. Any increase of oxygen in the blow immediately affected the content of combustibles in the gas and, consequently, its calorific value. Oxygen was the means of controlling the process of underground gasification from the surface.

The regenerative process is next described. Here the oxygen blow is replaced by an alternative air and steam blow or oxygen and steam blow. The periods alternate quite regularly, but because of the large volume of underground sidings do not alternate often.

When air is being blown in, the upper layer of the coal bed becomes heated and accumulates the heat. The air gas, or rather the gas of the hot blow, is of low heat capacity, and can be used for steam raising in boilers. Generally speaking, it pays to run the process in such a manner that during the period of hot blow the gas should contain a minimum of combustible components, because in this way the heating of the coal bed will be most efficient.

For the utilization of underground gas, two methods have been suggested. Gas of low heat capacity, received during the air blow, can be used for burning under boilers or in gas engines. In Kharkoff, Makovsky is developing a powerful gas turbine to operate on underground gas. By burning the gas under boilers or in gas turbines, the energy contained in the gas can be transformed into electrical energy, which can be supplied over large distances. However, in some cases, the direct supply of gas to the consumer may prove more profitable. (*The Steam Engineer*, vol. 5, no. 60, September, 1936, pp. 487–488)

SPECIAL MACHINERY

Silent Riveting Machine

THIS article describes a riveting apparatus recently developed by the Hannifin Manufacturing Co., of Chicago, Ill., which utilizes the hydraulic method of riveting.

With this method rivet heads are formed quietly by a single powerful stroke of the heading tool. Rivets can be headed either hot or cold, and at unusually fast rates of production. In heading $^3/_8$-in. rivets cold, for example, the complete operating cycle of the equipment takes only $2^1/_2$ sec. In one industrial plant where rivets are driven in line, 1000 rivets are headed an hour. The heading illustration shows a riveting operation on an automobile rear-axle assembly.

Hydraulic riveting equipment has been built in capacities from $7^1/_2$ to 50 tons, the smallest size being suitable for heading $^1/_4$-in. aluminum-alloy rivets cold, and the largest size $^7/_8$-in. rivets hot or $^5/_8$-in. rivets cold. Details of the machinery and operation are given in the original article.

Each riveting operation is controlled by a push button on the riveting yoke or machine, which the operator depresses to start the operation and holds depressed until the rivet has been headed. At the end of the cycle, the pressure is automatically relieved, and the push button must be released before the operation can be repeated. If the riveting tool does not descend in line with the rivet to be headed, because the rivet happened to be incorrectly placed or the riveting yoke wrongly positioned, the operator can instantly reverse the heading tool by merely releasing the push button. (Charles O. Herb, *Machinery* (New York), vol. 42, no. 12, August, 1936, pp. 761–764, 5 figs.)

TESTING AND MEASUREMENTS

Vaporization of Lubricating Oils for Internal-Combustion Engines

THE author points out that the determination of the ignition point of lubricating oils contributes no information as to their vaporizing ability, which, however, should be known, as it affects both the safety and economy of operation. He asserts that if two oils have the same viscosity, but one consists of a direct fraction and the other of a blend of bright stocks with a light machine of high ignition point, the latter, all things being equal, will show a higher consumption, and therefore be less economical.

On the other hand, however, such an oil, if the oiling devices have been fixed for economic consumption, will, after a while, because of the high evaporation, leave such a thin film that the lubrication and cooling of machine surfaces will be endangered.

The author reviews a number of laboratory methods and describes in detail his own process. In this latter 65 grams of oil are heated for an hour by electric-resistance elements to 250 C in a brass crucible equipped with a screwed-on head. The oil vapor generated is carried by an air stream flowing through three holes 2 mm in diameter in the crucible cover. The air stream may be induced by a water jet or oil pump. The air stream is so regulated that it shows the same water-level difference of 20 mm during the entire test on a water-filled manometer open on both sides. (Dr. K. Noack, Berlin. Original publication issued by the Reich Chemico-Technical Institution, abstracted through *Angewandte Chemie*, vol. 49, no. 25, June 20, 1936, pp. 385–388, 1 fig.)

LETTERS AND COMMENT

Brief Articles of Current Interest, Discussion of Papers, A.S.M.E. Activities

Modern Tolerance Requirements and Their Scientific Determination

To the Editor:

This excellent paper[1] cannot be too highly commended. It outlines in clear and logical form many important considerations relating to gaging which are frequently neglected and misunderstood. The discussion of the effect of eccentricity in holes and shafts is particularly illuminating and the author's instruments and methods for dealing with this problem are of great interest.

These comments will be confined to but one of the topics covered in the paper, the measurement of surface character by the device developed by the author and shown in Figs. 4 and 5 of the paper under review. This novel method of measuring surface quality is of great interest and a separate and more complete discussion of this apparatus and of the results obtained with it would be welcome.

In particular, it would be of interest to know the size and character of the measuring point employed to apply pressure to the specimen and the effect upon the results of changes in the radius of this measuring surface, particularly in the light of Hertz's theory. It would also be of interest to know how completely the results support the statement that the measurements are independent of the hardness of the material. One would expect this to be true, provided the surface character was such that no plastic deformation occurred under the loads applied. While this condition should be generally satisfied, it would seem possible that in some surfaces it would not hold and that the result would then depend upon the hardness.

Finally, it would be of great interest to know if there are data comparing the results obtained with this instrument with measurements of the surface profile obtained by such apparatus as that developed by Abbott and Firestone. The studies of these latter authors have shown that surface character can only be completely described by the curve of bearing surface vs. depth, and at least two parameters are required to define this curve. It would be of interest to determine what characteristics of the bearing surface vs. depth curve are correlated with the single quantity measured by Mr. Törnebohm's device. This apparatus evidently lends itself to various modifications and elaborations of procedure without any loss of its essential simplicity and ease of application. For these reasons, it offers great promise of usefulness in the development of methods for measuring surface quality.

R. L. Peek, Jr.[2]

[1] "Modern Tolerance Requirements and Their Scientific Determination," by Hilding Törnebohm, Mechanical Engineering, July, 1936, pp. 411–417.

[2] Bell Telephone Laboratories, New York, N. Y.

To the Editor:

In regard to Mr. Peek's inquiry about the device for measuring the surface quality described in my paper[1] in your July issue I would like to offer the following explanation:

I first want to say that I felt somewhat uncertain when demonstrating the device at the Dallas meeting and consequently also when describing it in Mechanical Engineering, as in my opinion it cannot be recommended at this time for practical use in its present state. I had, however, been working on producing such an instrument for several years and had advanced quite far in developing a principle which, however, is still impaired by certain imperfections that need to be removed. At Dallas I had an excellent opportunity to say a few words about the instrument in connection with other questions of measuring technique, and I therefore gave an account of an apparatus which is still in an experimental stage, but which is based upon a quite new principle. This principle is to use the source of error, that is involved when ordinary measurements are compared, that the surface characters of workpieces vary and their dimensions may be compared with one another, as, for instance, by comparing an ordinary workpiece with a reference disk.

My first experiments were carried out with the familiar Zeiss ultraoptometer. It is quite easy to apply a loading device on the measuring point of such an apparatus, thus obtaining different measuring pressures. The instrument being graduated by 0.2 μ, readings of an accuracy of 0.05 μ can be made. The difficulty is, however, that the workpiece must be placed on a measuring table and the deformation arising at the contact between the workpiece and the table is therefore included in the reading. The side of the workpiece to be placed against the table must therefore be made with block-gage accuracy. Similar arrangements can surely be made on the well-known and exceedingly accurate Sheffield gage.

I mention these first experiments, because they can be performed by any one interested in this method of measurement. If Mr. Peek acts in accordance with these directions he will obtain answers to most of his questions. By a similar device it can easily be verified whether the deformations, caused by placing a measuring point on a workpiece, are plastic or elastic, the condition naturally depending on the loads and measuring points employed. For my experiments I have been using spherical measuring points of 2.5-mm, 5-mm, and 10-mm radius and the pressure, at one time, of the ultraoptometer itself, about 300 g, and at another a pressure of 1300 g, obtained by adding a weight of 1 kg to an arm attached to the measuring point.

Mr. Peek will find that a certain plastic deformation always arises even when the measuring points are large and particularly accurate workpieces, such as block gages, are measured.

Suppose the optometer, the dial indicator, or the Sheffield gage be adjusted to 0 exactly at a pressure of 300 g. If the pressure is then increased by 1 kg, the measuring point will move, say, 1.2 μ and the indicator stops at -1.2 μ, i.e., the indicator point has moved six divisions of 0.2 μ each. If the supplementary load is removed, the pressure is consequently reduced to 300 g, the pointer returns not exactly to 0 but just below, e.g., -0.10 μ. If the load is then applied again, the reading will be about -1.25 μ. I have used the value $\delta = 1.15\,\mu$ instead of 1.2 μ when calculating accord-

ing to Hertz' theory. Briefly, I have always made a second reading, as it is risky to rely on the first one, and this second reading has been decisive for the surface quality.

It will be seen from this example that a certain deformation has been verified, which, however—provided appropriate measuring pressures and measuring points are employed—is comparatively unimportant. The plastic deformation of inferior workpieces does not, as a rule, amount to a higher relative value than that, for instance, of gage blocks, regardless of whether they are hardened or not.

One of the most important problems that still remains to be settled is to effect a smooth loading device that will work without any shocks whatever. I am studying this problem at present and I have already improved the instrument, demonstrated at Dallas, by an elastic loading device. The principal requirement is to avoid shocks, as they seem to effect plastic deformations. A pneumatic or hydraulic loading device may be the correct method; however, this is an assumption the truth of which can only be verified by repeated experiment.

To Mr. Peek's last question if there are data comparing the results obtained with this instrument with measurements of the surface profile obtained by such apparatus as that developed by Abbott and Firestone, I beg to say that as far as I know no such data exist, but I entertain hopes that such comparative experiments may be made before long.

H. TORNEBOHM.[3]

Mr. Ferris' Questions

TO THE EDITOR:

The case for continued reliance upon competition—upon "dollar votes"—as the governing mechanism for the business system is stated with force and clarity by Ralph E. Flanders in his recent book, "Platform for America."

This letter is written by one who believes with the author that government should avoid the "hopeless and impossible endeavor to regulate the details of . . . . business by legislation."

However, Mr. Flanders proposes that government should intervene in the competitive business system at certain critical points, for instance, to force competition by suppressing attempts to maintain or raise prices by agreement. Likewise he suggests policies which would limit competition based upon exploitation of labor by means of wage cutting. He favors a control of the nation's credit, in order to channel it into productive use instead of speculation.

The present correspondent wishes to suggest that to this list must be added measures to protect our agricultural land, a vital natural resource, against the free action of competition.

The competition advocated by John Stuart Mill actually existed in American agriculture in almost pure form until the establishment of the ineffective Farm Board in the middle twenties. It was not until 1933 that government intervention was really felt.

The play of economic forces impinges upon the land indirectly through the agricultural population. Competition means one thing for agriculture and quite another thing for the highly organized businesses in manufacturing and distribution.

Between 1929 and 1933, for instance, it meant that prices of agricultural commodities dropped 63 per cent, and output dropped 6 per cent. That is to say, when people could no longer pay the farmer as much as the farmer expected to get, competition forced him to drop his price to what the consumer could pay. The farm "plant" continued to produce at practically normal output.

The effect of competition in the agricultural-implements business, to take an extreme case on the other side, was quite different. Prices dropped only 6 per cent while output dropped 80 per cent during the same four years, although there was no absence of competition. Typically, industry does not, for some reason, reduce prices during depressions sufficiently to enable normal volume of output to be maintained. Farmers, for instance, got very little agricultural machinery in 1932, although people continued to get about as much wheat in 1932 as they had in 1929.

The consequences of this situation have a profound significance that is frequently missed. Farmers are not only producers and consumers; they are the stewards of the most fundamental of all of our natural resources—the land.

"If you squeeze the farmer, he squeezes the land." The operation of competition over a period of many decades finally brought millions of the agricultural population to a position where they were practically forced to follow practices which are rapidly destroying the nation's heritage of topsoil. It is easy for a manufacturer to see that it is useless to get his income by selling a wing of his factory every year. The farmer's plant, however, is the stored productivity of centuries in the soil. The increments of accelerating destruction are scarcely visible, particularly to the city man, who has only recently seen dust storms from the West and begun to sense that he too has a stake in what happens to the land.

With this long preface the following questions are addressed to Mr. Flanders:

How can the nation's agricultural land be protected without some degree of government intervention in the competitive struggle between large-unit business and small-unit farming? Should the economic survival of the farmer depend only upon the quantity, quality, and cost of his current output, or should it depend also upon the condition in which he turns over America's agricultural plant to the next generation?

JOHN P. FERRIS.[4]

Mr. Flanders' Answer

TO THE EDITOR:

There seem to me to be two main elements to the inflexibility of industrial vs. farm prices. One is fixed charges, which include debt servicing, insurance, and taxation, and the other labor cost. Material cost, of course, comes into it, but this in turn is composed principally of the preceding elements. All of these elements are unresponsive to change as compared with the farmers' business with its direct personal management and immediate contact with natural resources. A principal point in the comparison seems to me to be the relative flexibility of the farmer's labor costs. When he sells wheat for 30 cents a bushel, he is giving his labor away. The industrialist making, for instance, farm machinery, cannot build that machinery on the basis of free labor. Isn't this the largest element in the comparison?

It seems to me that the cooperative movement offers the best yardstick and safety valve (to mix figures a bit) for the capitalistic system. It should be rigorously protected by government from unfair competition. It should have no governmental subsidy. Those interested in it should push it to the limit of its commercial practicability. "Private" business should be spurred by it as by any lawful competitor and should not fight it as an undesirable institution.

The first safeguard against exploitation of the soil is the ownership of the land by the man who works it. It is proper that governmental policies should be directed toward the assistance of farm ownership and the discouragement of

[3] A. B. Svenska Kullagerfabriken, Goteborg, Sweden. Third Calvin W. Rice Memorial Lecturer.

[4] Norris, Tenn. Mem. A.S.M.E.

farm tenancy. As to the second point, there are differences as between the labor conditions of farm and industry and also the conditions under which farms and industries are thrown into bankruptcy which will always make industrial prices less variable than are farm prices. The remedy for this seems to me to lie in the maintenance of that balance between farm and factory which I tried to describe in my little book. If we can approach that balance, reverse the trend toward tenancy, and educate the farm owner, we have a natural rather than an artificial means of preserving the fertility of our soil.

The dangerous element in any endeavor to protect an unsocial condition by subsidy is that unbalances are perpetuated instead of being adjusted. Most of the recent proposals for soil conservation seem to be of this character. Perhaps a little more ingenuity will discover more satisfactory pol'cies.

R. E. FLANDERS.[5]

Growth of Fatigue Cracks

TO THE EDITOR:

In his discussion of a paper[6] entitled "The Rate of Growth of Fatigue Cracks," Thomas C. Rathbone describes the restoration of the natural frequency

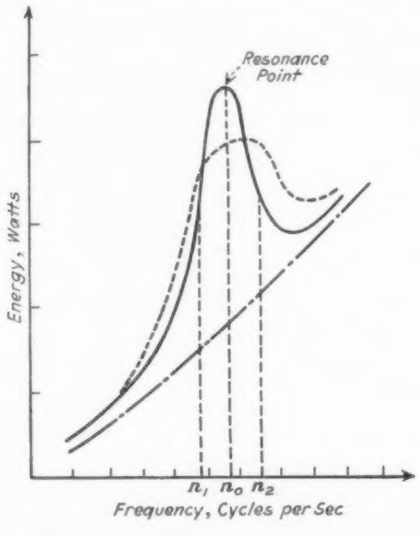


FIG. 1 ENERGY-FREQUENCY CURVE

(Solid line refers to uncracked specimen; dotted line to cracked and painted specimen. Resonance period = n_0. Damping angle, tau = $(n_1 - n_2)/n_0$)

[5] President, Jones & Lamson Machine Co., Springfield, Vt., Past-President, A.S.M.E.

[6] "The Rate of Growth of Fatigue Cracks," by A. V. de Forest, *Journal of Applied Mechanics*, March, 1936, Trans. A.S.M.E., vol. 58, pp. A-23–A-25. Discussion by Thomas C. Rathbone, Ibid., September, 1936, pp. A-114–A-115.

by applying kerosene and whiting on a fatigue crack.

In tests carried out by the writer, alternating forces of a sine form excited by the centrifugal forces of two eccentrically supported rotating disks were used to oscillate the test specimen in forced vibration. The input and the revolutions of the electromotor driving the rotating disks were combined to a so-called energy-frequency curve (Fig. 1). These energy-frequency curves gave exactly the same results which Mr. Rathbone shows in Fig. 3 of his discussion. Minute cracks, even not visible under the microscope, caused a distinctly pronounced drop in the resonance point indicated by the energy-frequency curve, changing the elastic constant of the vibrating system.

Painting the surface of the specimen restored in certain cases the natural frequency, but substantially broadened the width of the energy-frequency curve. The width of this curve has been frequently used to determine the damping effect. The tangent of the damping angle is approximately equal to the difference of cycles per second in the middle of the curve divided by the natural frequency. Hence the curve in Fig. 3 of Mr. Rathbone's discussion indicates an increase in damping of about $3^1/_2$.

The "mysterious way" in which this restoration was effected is explained by the penetration of the paint in the minute crack, where it acts as a rather rigid and effective glue which absorbs a certain amount of tension and compression. On the other hand, the paint forms an additional damping device.

R. K. BERNHARD.[7]

[7] Consulting Engineer, Philadelphia, Pa.

A.S.M.E. BOILER CODE

Interpretations

THE Boiler Code Committee meets monthly for the purpose of considering communications relative to the Boiler Code. Any one desiring information on the application of the Code is requested to communicate with the Secretary of the Committee, 29 West 39th St., New York.

The procedure of the Committee in handling the cases is as follows: All inquiries must be in written form before they are accepted for consideration. Copies are sent by the Secretary of the Committee to all of the members of the Committee. The interpretation, in the form of a reply, is then prepared by the Committee and passed upon at a regular meeting of the Committee. This interpretation is later submitted to the Council of The American Society of Mechanical Engineers for approval, after which it is issued to the inquirer and published in MECHANICAL ENGINEERING.

Following are records of the interpretations of this Committee formulated at the meeting of September 18, 1936, and approved by the Council.

CASE No. 831

(*Interpretation of Par. P-325*)

Inquiry: May double hanger brackets be attached to welded horizontal-return tubular boilers by fusion welding provided: the lower ends of such brackets are not more than 20 deg above the horizontal center line and extend over an arc

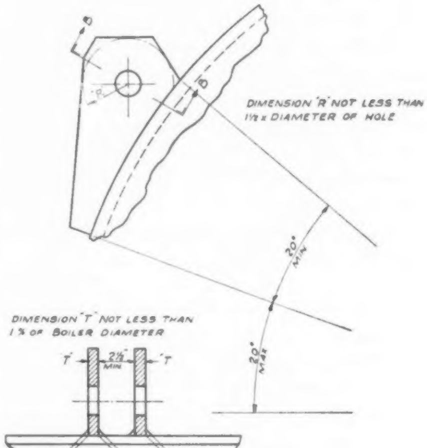


FIG. 33 WELDED BRACKET CONNECTION FOR HORIZONTAL-RETURN TUBULAR BOILER

of not less than 20 deg for shells of any diameter; the bracket plates to be spaced at least $2^1/_2$ in. apart, thickness of each bracket plate to be not less than 1 per cent of the shell diameter, the hanger pin to be located on the vertical center line over the center of the welded contact surface; the distance from the center line of the hanger pin to the edge of the bracket to be not less than $1^1/_2$ times the hole diameter; and the welding and stresses to meet the requirements of Par. P-325c? Fig. 33 shows such construction as applied to a 72-in. diameter boiler.

Reply: It is the opinion of the Committee that the construction outlined in the inquiry meets the intent of the Code requirements.

CASE NO. 832

(*Interpretation of Par. P-329*)

Inquiry: Is it the intent to require hydrostatic test of the completed boiler unit, if the drums are of fusion-welded construction in accordance with Par. P-109*b*?

Reply: Pars. P-101 to P-111, inclusive, are, as titled, "Rules for the fusion process of welding" drums or shells of power boilers and apply only to such individual parts. The hydrostatic test pressure of a completed boiler unit should not exceed that provided for in Par. P-329.

THIS MONTH'S AUTHORS

THE collaborators of the paper describing the "Steamotive" represent not only the companies responsible for the joint development of this interesting aspirant for a locomotive power unit but also the departments of engineering science upon which the success of the device depends—the boiler, the turbine and turbine-driven auxiliaries, and the automatic control. All three collaborators are members of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

E. G. BAILEY, founder and president of the Bailey Meter Company, has been known for years as an expert in combustion, particularly of powdered fuel, and of flow meters and combustion-control devices. His early engineering experience following graduation from Ohio State University was with the Consolidated Coal Co. of Fairmont, W. Va., and the Arthur D. Little Co., of Boston. From 1909 to 1915 Mr. Bailey was mechanical engineer and partner in the Fuel Testing Co., Boston. In 1916 he founded the Bailey Meter Company, and since 1926 has been president of the Fuller-Lehigh Company. He is known to combustion and boiler engineers for the Bailey blocks applied to furnace waterwalls, and as vice-president of the Babcock and Wilcox Company.

A. R. SMITH, managing engineer of the turbine engineering department and of the construction engineering department of the General Electric Company, has been associated with that company since 1897. In 1912 his services were loaned to the Newport News & Hampton Railway Gas & Electric Company on a comprehensive engineering reconstruction project. In 1914 he was sent to Chile by the General Electric Company in connection with the design and installation of a steam-electric plant and the electrification of a mining railway at the iron mines of Bethlehem Steel at Cruz Grande. In 1929 he went to Russia in the company of other General Electric engineers to assist the U.S.S.R. in planning electrical manufacture and development on a national basis. In 1930 he took over the development of the mercury-vapor process.

PAUL S. DICKEY, since 1933, has been director of research for the Bailey Meter Company. He was graduated from Purdue University in 1925 with the degree of B.S. in mechanical engineering, and became development engineer for the Bailey Meter Company, in charge of automatic combustion-control equipment.

The major portion of this month's issue is devoted to a group of eight papers that are to be presented at the 1936 Annual Meeting of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS as a symposium on corrosion-resistant metals.

F. N. SPELLER, member, A.S.M.E., who prepared the introductory paper of the symposium and who is director of the department of metallurgy and research of the National Tube Company (subsidiary of the U. S. Steel Corporation), received the degrees of Bachelor of Applied Science and Doctor of Science from the University of Toronto, Canada. After several years of general engineering experience, including the position of chemist of the City of Toronto, he worked in the mills of the Carnegie Steel Company. This was followed by mining engineering work in Alaska and association with the Bureau of Mines of Ontario. He began his service with the National Tube Company in its chemical laboratory at McKeesport, Pa. in 1901. Mr. Speller is the author of many papers on the subject of corrosion of metals, and of a book on "Corrosion—Causes and Prevention" the second edition of which appeared in 1935.

EDGAR H. DIX, JR., coauthor with R. B. Mears of the paper on "Corrosion-Resistant Aluminum and Its Alloys" is chief metallurgist of the Aluminum Research Laboratories of the Aluminum Company of America. He received the degrees of M.E. from Cornell University in 1914 and M.M.E. in 1916, and during that two-year period he served as an instructor in engineering materials and materials testing. He then served successively with the Morse Chain Works, the Baltimore Copper Smelting and Rolling Company, the Bureau of Aircraft Production, the Aluminum Castings Co., and the Engineering Division of the Air Service, U. S. Army. In 1923 Mr. Dix became associated with the Aluminum Company of America as metallurgist in charge of the New Kensington Metallurgial Division of the Aluminum Research Laboratories. He is a member of the American Society for Testing Materials, of the American Institute of Mining and Metallurgical Engineers (Chairman of Pittsburgh Section and Metals Division), a member of the American Society for Metals, of the British Institute of Metals, and of the American Foundrymen's Association.

ROBERT B. MEARS, of the Metallurgical Division of the Aluminum Research Laboratories, received the degree of B.S. in electrochemical engineering from Pennsylvania State College in 1928. He was then for four years a member of the technical staff of the Bell Telephone Laboratories. From 1932 to 1935 Mr. Mears studied at Cambridge University, England, where he received his Doctor's degree in metallurgy. He is a member of the Electrochemical Society.

GEORGE O. HIERS, author of the paper on lead, and member of the A.S.M.E., is metal technologist in the research laboratories of the National Lead Company, Brooklyn, N. Y. He attended the Polytechnic Institute of Brooklyn from 1911 to 1916. Mr. Hiers started his present employment in 1911 as apprentice chemist, and from 1915 to the present time has specialized in work on lead, tin, and their alloys regarding their properties and uses. He is author or coauthor of numerous papers published by A.C.S., A.E.S., A.I.M.E., and A.I.Ch.E. He is an active member of A.I.M.E., A.C.S., and A.S.T.M. and a fellow in A.A.A.S.

EDMUND ARNOLD ANDERSON, author of the paper on zinc, was graduated from the mining-engineering course at Yale University in 1920 and received his master's degree in physical metallurgy from the same institution in 1923. Before undertaking postgraduate work, he had spent a year and a half in research on white-gold alloys and silver solders with Handy & Harman, Bridgeport, Conn. In 1923, Mr. Anderson became an investigator in the Research Division of The New Jersey Zinc Company. In this organization, he has been active in the development of zinc-base alloys for die casting and in studies of corrosion, plating, and metal-finishing problems. Since 1928, his title has been chief of metal section, research division. He is an active member of the Research Committee of the American Electroplaters' Society, a member of several A.S.T.M. committees, and a member of the A.I.M.E. and has contributed frequently to technical literature. He was a coauthor of the paper which received the award for the best paper presented before the Institute of Metals Division of the A.I.M.E. in 1934–1935.

H. L. MAXWELL, author of the paper on cast iron, was graduated from Cornell University in 1916, and in 1917 received the degree of M.S. from the same institution. He entered military service, doing technical microscopic work, in 1919; and then resumed graduate study at Iowa State College, teaching part time, specializing in thermodynamics, chemical engineering, and metallurgy. He was granted the degree of Ph.D. in 1924. He continued teaching for two years. In 1926 he accepted a position as associate professor of chemical engineering and research associate at Purdue University. After four years at Purdue University Mr. Maxwell accepted a position as metallurgist with the ammonia department of E. I. du Pont de Nemours & Company,

Wilmington, Delaware, and in 1933 was advanced to chief metallurgist of the parent company, which position he now holds. He is a member of numerous honorary, technical, and social fraternities, including American Society for Metals, American Society for Testing Materials, American Chemical Society, American Society for Advancement of Science, Iowa Academy of Science, and Indiana Academy of Science. He has contributed to the technical literature in the fields of chemical engineering equipment, metallurgy, and corrosion-resistant materials.

R. A. WILKINS, who prepared the paper on copper and copper-base alloys, was graduated from the Massachusetts Institute of Technology in 1918. During the war he served in the development division of the Chemical Warfare Service in command of the Chemical Laboratory Offense Section. Following the War he became chemical engineer of the Lignite Laboratories, Cleveland, Ohio, and later instructor in mathematics and chemistry, in the Chauncy Hall School, Boston, Mass., and then assistant professor of chemical engineering at the Massachusetts Institute of Technology. Entering industrial work once more Mr. Wilkins became vice-president and research director of the Industrial Development Corporation and later vice-president and director of research of the Revere Copper and Brass Company, Utica, N. Y., the position he now holds. He is a member of the American Society for Testing Materials, American Institute of Mining and Metallurgical Engineers, American Chemical Society, and British Institute of Metals.

J. H. CRITCHETT, who writes on stainless steels and irons, was graduated from the Massachusetts Institute of Technology, department of electrochemistry, in 1909. His early work was connected with the then young electric steel industry in the United States, first as melter and then, assistant superintendent of the department at Illinois Steel Company, South Chicago. Following this, he had charge of construction and initial operations of Buchanan Electric Steel Foundry, now Clark Equipment Company. In 1914 he joined the technical staff of Electro Metallurgical Company, carrying on research and development work on ferro alloys. When Union Carbide & Carbon Research Laboratories, Inc., was formed in 1921, he was transferred to that organization and is now its vice-president. He is past president of the Electrochemical Society, member of numerous technical societies, and has presented many papers before them on metallurgical subjects.

F. L. LAQUE, who presents the paper on nickel and nickel alloys, is associated with the development and research division of the International Nickel Company, Inc., New York, N. Y., specializing in corrosion problems. He was graduated from Queens University, Kingston, Ontario, Canada, in 1927, where he received the degree of bachelor of science in chemical and metallurgical engineering. He is author of numerous papers related to the field in which he is engaged and is a member of technical committees of the American Society for Testing Materials, Technical Association of the Pulp and Paper Industry, and the American Society of Heating and Ventilating Engineers.

ALBERT A. SCHAEFER, professor of law and government, contributes this month's review of books on economics of interest to engineers. He is a member of the department of business and engineering administration at the Massachusetts Institute of Technology. He is a graduate of Harvard College and of the Harvard Law School, and has made a specialty of business law and government.

One of his colleagues writes of him as follows: Professor Schaefer has been on the staff of the Department of Business and Engineering Administration on a part-time basis for several years. For many years he has been associated with Ropes, Gray, Boyden, and Perkins, where he has specialized in the trial of cases. In 1935 he became a full time member of the staff, to which he has become a notable addition. Unlike most professors, he has a hard time getting away from his classes. During the World War he was the Director of Enforcement of The England Fuel Administration under appointment by President Wilson, and also the Legal Adviser of the local Draft Board. He is a collaborator on "Organization and Management of a Business Enterprise."

REVIEWS OF BOOKS

And Notes on Books Received in the Engineering Societies Library

Engineering Fundamentals

HANDBOOK OF ENGINEERING FUNDAMENTALS. Edited by Ovid W. Eshbach. John Wiley & Sons, Inc., New York, N. Y. Semiflexible cloth, $5^1/_2 \times 8^1/_2$ in., 1081 pp. Trade edition \$5, college edition \$4.

REVIEWED BY FRANK L. EIDMANN[1]

THIS handbook has been prepared by forty contributors, with Ovid W. Eshbach as editor in chief, for the purpose of embodying in a single volume those fundamental laws and theories of science which are basic to engineering practice. As Volume I of the Wiley Engineering Handbook Series, it is intended to contain the fundamental material which is common to all branches of engineering, and the several other volumes in the series are to cover the specialized branches such as Power; Design and Shop Practice; Electrical Power, Communication, and Electronics.

The volume consists of 13 sections as follows: Mathematical and physical tables, mathematics, physical units and standards, theoretical mechanics, mechanics of materials, mechanics of fluids, engineering thermodynamics, electricity and magnetism, radiation and light, acoustics and meteorology, chemistry, metallic materials, nonmetallic materials, and contracts.

The handbook is an important contribution to engineering literature, and the editor, contributors, and publishers are to be congratulated. There has long existed a recognized need for a handbook of this type, which is essentially a summary of textbooks. Graduates and students in engineering have often expressed their desire for a single reference volume covering the science fundamentals in condensed form for purposes of quick review. Unfortunately, however, in the work under review, some subjects have been condensed to such a degree that their treatment is rather sketchy. In considering the volume critically this reviewer believes that the usefulness of the book would be considerably enhanced by the inclusion of more tables of fundamental information, more definitions, and the discussion of certain additional subjects. Engineers are finding a growing need for organic chemistry, and a discussion of the fundamentals would be of value. All engineers must be cost-minded, and a consideration of the fundamentals of so-called engineering economy, or financial analysis of engineering projects, would therefore be useful. Also, the following are among those topics of fundamental importance which should be included: The chemistry of combustion; a table of the heat values and analyses of various

[1] Professor of Mechanical Engineering, Columbia University, New York, N. Y. Mem. A.S.M.E.

solid, liquid, and gaseous fuels together with data regarding the amount of air required for combustion; a table of ignition temperatures for gaseous mixtures; a table of flame temperatures; one of atmospheric density at different altitudes; solution of solids in liquids and effect on boiling point and freezing point; coefficients of cubical expansion of liquids; mixtures of liquids and their effect on properties; velocity of sound in liquids and gases; values of acceleration due to gravity with variations of altitude and latitude. Theories of lubrication deserve discussion, as also do the theory of the gyroscope and the fundamentals of vibrations. It would be time-saving to have in a single table the mechanical properties of materials instead of having them scattered through the book. Discussions of machining, forging, soldering, and welding seem unnecessary in this book. No mention is made of asbestos as a friction material. The coefficient of friction of cork and asbestos brake lining on metals should be included in tables. Graphical methods of computation should include mention of the use of logarithmic and semilogarithmic cross-section paper. Definitions of such terms as specific gravity, hydrometer scales, center of buoyancy, and metacenter should be given. The complexity of section 3 on physical units may result in confusion to the average user.

Although business law is not a fundamental of engineering, the inclusion of the section on this subject should be useful to the engineer. It is to be regretted, however, that the essentials of patent law are not discussed. A typical code of ethics for engineers might also be included. Under "the engineer as expert witness" one would expect to learn the legal distinction between an expert witness and an ordinary witness.

Even though a primary object of this handbook is the removal of material of a fundamental nature from the specialized handbooks, there must of necessity be considerable repetition in order to make each handbook a reasonably complete and independent volume. The publishers apparently recognize this, for in the newly published Kent, volume 2 on power, 58 pages of mathematical tables are included and there are numerous other examples of necessary repetition. One minor instance is a chart which appears in Eshbach and which is repeated twice in volum 2.

It should not be inferred from these comments that the reviewer is unfavorably impressed with the book. Quite the contrary. The scope of the book is broad; the treatment of the subjects is, in general, clear; the format is excellent; the index is fairly complete; and the bibliography is valuable, although in some instances important books in the respective fields under discussion are not listed. This handbook should prove invaluable for quick review of the fundamentals of science which concern the engineer.

Books Received in Library

ALUMINUM PAINT AND POWDER. By J. D. Edwards. Second edition. Reinhold Publishing Corp., New York, 1936. Cloth, 6 × 9 in., 216 pp., illus., charts, tables, $4.50. This volume, a successor to "Aluminum Bronze Powder and Aluminum Paint," is essentially a new book, being double the length of its predecessor and including the additional developments of the last nine years. The manufacture and properties of aluminum powder, the composition, properties and uses of aluminum paint, and the other industrial uses of aluminum powder are described.

A.S.T.M. STANDARDS ON PETROLEUM PRODUCTS AND LUBRICANTS, prepared by Committee D-2 on Petroleum Products and Lubricants. September, 1936. American Society for Testing Materials, Phila. Paper, 6 × 9 in., 372 pp., illus., diagrams, charts, tables, $2; to members, $1.50. This compilation gives 56 test methods, five specifications, and two lists of definitions in their latest approved form. It also discusses the changes made in the standards and some proposed new methods for determining kinematic viscosity and neutralization number.

ATM—Archiv für technisches Messen, Lieferung 59-62, May-August, 1936, R. Oldenbourg, Munich and Berlin. Paper, 8 × 12 in., illus., diagrams, charts, tables, 1.50 rm. each. This publication continues to provide a review of measurement methods, instruments, and accessories in convenient form for reference. Brief articles by specialists on methods and manufacturers' descriptions of new equipment are included. The material is in loose-leaf form, each article having classification numbers by the Universal Decimal system and by a special system, thus enabling the user to bring similar articles together without effort.

AIRPLANE AND ENGINE MAINTENANCE FOR THE AIRPLANE MECHANIC. By D. J. Brimm and H. E. Boggess. Pitman Publishing Corporation, New York and Chicago, 1936. Cloth, 6 × 9 in., 493 pp., illus., diagrams, charts, tables, $2. This book, the work of two instructors in the New York City School of Aviation Trades, offers a thorough, practical course for the airplane mechanic, based upon teaching experience. Numerous practice jobs are provided, with detailed directions and instruction in the use of tools. The text is intended for home study and use in trade schools, and as a work of reference for the licensed mechanic.

DIAMANT-WERKZEUGE. By P. Grodzinski. M. Krayn Verlag, Berlin, 1936. Bound, 4 × 6 in., 214 pp., illus., diagrams, charts, tables, 6.50 rm. This little book brings together an account of the industrial uses of the diamond for cutting and grinding metal, sawing stone, drilling wells and drawing wire, for bearings in instruments, engraving, gem cutting, glass working, etc. The information is practical and definite, and the subject is covered comprehensively, apparently for the first time in book form.

ENGINEERING AERODYNAMICS. By W. S. Diehl. Revised edition. Ronald Press Co., New York, 1936. Cloth, 6 × 9 in., 556 pp., illus., diagrams, charts, tables, $7. So much new material has been made available by aerodynamic research work and experimental construction since the first edition of this book appeared in 1928 that this edition is essentially a new book. It aims to supply the designer and advanced student with concise, practical information on the dynamics of airplane design, presented in convenient form for use.

FORSCHUNGSHEFT 380. WÄRMEÜBERGANG UND REIBUNGSWIDERSTAND BEI GASSTRÖMUNG IN ROHREN BEI HOHEN GESCHWINDIGKEITEN. by I. Jung. V.D.I. Verlag, Berlin, September-October, 1936. Paper, 8 × 12 in., 26 pp., illus., diagrams, charts, tables, 5 rm. According to the author, the data hitherto available upon heat transfer and frictional resistance of gas flow have only been provided for velocities up to about 100 ft per sec. The present investigation was undertaken to obtain data for higher velocities. Experimental results for velocities from about 300 to 1200 ft per sec are given.

HANDBOOK OF CHEMISTRY AND PHYSICS. Twenty-first edition. Edited by C. D. Hodgman. Chemical Rubber Publishing Co., Cleveland, Ohio, 1936. Leather, 4 × 7 in., 2023 pp., tables, $6. The latest annual edition of this well-known reference book has been carefully revised, over 175 pages of new composition having been used. The numerical table has been replaced by a new form and a table of haversines provided. The section on laboratory arts and recipes has been revised and enlarged. Much material has been added to the photographic section. A useful table on the properties of plastics has been added. The volume is an invaluable reference book for the laboratory bookshelf.

HIGH-SPEED DIESEL ENGINES. By L. H. Morrison. American Technical Society, Chicago, 1937. Cloth, 6 × 9 in., 243 pp., illus., diagrams, charts, tables, $2.50. This is a simple, practical test on the construction and operation of these engines, intended to inform the reader about the way each type functions and instruct him in the fundamentals of operation and maintenance. Details are given for thirteen American makes, as well as several European aviation and truck engines.

THEORY OF THE PROPERTIES OF METALS AND ALLOYS. By N. F. Mott and H. Jones. Oxford, England, Clarendon Press; New York, Oxford University Press, 1936. Cloth, 6 × 10 in., 326 pp., diagrams, charts, tables, $8. The aim of this work is to give as complete an account as possible of the present state of the electron theory of metals and of its successes in accounting for the observed properties of metals and alloys. Recent developments in the quantitative calculation of metallic bonds and the prediction of the crystal structure and phase equilibrium diagrams of alloys are described, and there are accounts of the specific heats and thermal expansion of solids, the optical properties and colors of metals and alloys, and their magnetic properties and electrical conductivity. Special attention is given to metals with abnormal properties.

A.S.M.E. NEWS

And Notes on Other Engineering Activities

A.S.M.E. Participates in Metal Week at Cleveland

Technical Papers on Welding Presented Oct. 22 and 23

IN COOPERATION with the American Society for Metals, Institute of Metals, and Iron and Steel Division of the American Institute of Mining and Metallurgical Engineers, the Cleveland section of The American Society of Mechanical Engineers, and the Machine Shop Practice, Iron and Steel, Applied Mechanics, Petroleum, and Process Industries Divisions of the Society, participated in the eighteenth National Metal Congress and National Metal Exposition held in Cleveland, October 19 to 24.

The A.S.M.E. was specifically concerned in a two-day symposium on welding practice to which it contributed the eight papers published in the October issue of the Transactions, and two others. These sessions were held jointly with the American Welding Society in the Hotel Cleveland. On Thursday night A.S.M.E. members participated in the annual dinner of the American Welding Society.

The technical program was arranged jointly with the American Welding Society. C. E. Obert, George Nordenholt, and R. E. Peterson represented the A.S.M.E., and E. S. Ault the A.S.M.E. Cleveland Section.

Over a Hundred Papers Presented

Because of the number of technical and engineering societies participating in the Congress, the total number of papers was well over one hundred, and attendance was unusually large. At the National Metal Exposition, held in the Lakeside Exposition Hall, 212 exhibitors occupied 165,000 sq ft of floor space and attracted a large attendance. Admission during the major portion of the exposition was limited to visitors especially interested in the displays. On the final day admission of the general public was permitted. Exhibitors expressed satisfaction at the amount of interest shown and in the business possibilities opened up by the exposition. Many new products were on display, as well as new processes, testing equipment, welding machines, and other metal-working machinery.

A.S.M.E. Technical Papers

The A.S.M.E. sessions opened with a paper by Charles H. Jennings on welding design in which the author discussed the selection of the proper joint, the calculation of weld stresses, the determination of working stresses and safety factors, and certain design details.

In a paper on welding alloy steels, A. B. Kinzel treated his subject under the general headings low-alloy steel for general structural purposes, heat-treated steels of the automotive type for machines and general engineering, and alloy steels, for the chemical industry.

W. L. Warner discussed the arc-welding of structural alloy steels, with extensive material drawn from the experience of the Watertown Arsenal. In a brief discussion H. G. Marsh said that two to three million tons of steel were welded last year and gave examples of the use of welding in the design and construction of machine tools. He also advanced reasons why its application is not more universal. In a paper on the welding of heavy machinery C. A. Wills and F. L. Lindemuth discussed the problems met with in designing, fabricating, and stress-relieving of welded machine parts and other types of welded equipment.

Three distinct fields of copper-alloy welding were surveyed by I. T. Hook in a paper on that subject: Joining of copper alloys by various brazing and welding methods; joining ferrous and other metals by the copper-alloy method; and building up wear and corrosion-resistant surfaces of copper alloys.

In the field of welding of other common nonferrous metals were two papers on the electric welding of monel and nickel, by F. G. Flocke and J. G. Schoener, and on the welding of aluminum alloys by G. O. Hoglund. In the paper on monel and nickel welding both the metallic-arc and carbon-arc methods were discussed, as was the welding of these metals to steel plate. Chemical and physical properties of monel and nickel, and of the deposited weld metal, were given. In discussing the welding of aluminum alloys Mr. Hoglund considered the use of gas, metallic-arc, and electric-resistance methods. He included references to the types and gages of aluminum alloys suitable for welding, difficulties encountered in the process, and methods used.

A discussion of the problems involved in choosing between a cast machine part and a part fabricated by welding for any specific purpose was presented in a paper by J. L. Brown. Mr. Brown discussed the advantages and disadvantages of each method in the light of the cost, utility, and appearance of the finished product.

Methods for the inspection of welds and welded structures were described in papers by H. R. Isenburger and Joseph W. Yant. Mr. Isenburger's paper was based on material presented in July, 1936, issue of Mechanical Engineering, pages 442–446, entitled "Radiographic Inspection of Welded Refinery Equipment." In this article Mr. Isenburger described the X-ray apparatus for inspecting pressure-vessel welds, portable equipment, and the technique of locating defects and interpreting results.

Magnaflux Inspection

Mr. Yant's paper, which was not received in time for publication before the meeting, was entitled "The Magnaflux Inspection of Pressure-Vessel Welds." It described applications of the Magnaflux method by the engineering department of the Standard Oil Company of Indiana, with which Mr. Yant is associated. The method was first applied by this company to alloy welds of vessels lined with ferretic stainless steel, and subsequently as a final test after the hydrostatic test for all welds of vessels not X-rayed and for X-rayed vessels after stress relieving.

In applying the method the pressure vessel is wrapped with 6 to 14 turns of welder's cable around its girth and the ends of the cable are connected to a welding generator producing a current of at least 300 amperes. With the vessel magnetized by the flow of current, magnaflux powder is sprinkled on the surface over the weld. When the plate alongside the weld is struck with a hammer the particles of powder arrange themselves in such a way as to line up over any defects present. Following this test, the vessel is wrapped with wires arranged longitudinally and is "magnafluxed" again. Both winding arrangements are necessary, as certain cracks may slow up with one and not with the other.

Mr. Yant quoted experiences with this method of testing to indicate that by means of it cracks had been discovered that failed to show up with X-ray inspection. The type of defect most readily indicated by the magnaflux test is a crack which extends to the surface of the weld. Cracks invisible to the naked eye have been indicated by this method.

Mr. Yant concluded that as a final test of vessel welds (such as those around nozzles and manways whose position makes X-raying impossible), as a final test of longitudinal and girth seems subsequent to radiographing and stress relieving, or as a final test of class 2 vessels, magnafluxing is of definite use in indicating cracks in welds. In his opinion it is a useful auxiliary to the X-ray test, and should a technique be developed which would locate subsurface defects more readily, could be of even greater utility.

A.S.M.E. Calendar

of Coming Meetings

November 30–December 4
Annual Meeting,
New York, N. Y.

May 14–15, 1937
National Rayon Textile
Conference, Washington, D. C.

May 17–21, 1937
Semi-Annual Meeting,
Detroit, Mich.

Local Sections Meetings
See page 864

Morehead Medal Awarded to Dr. D. S. Jacobus

THE Morehead Medal for the year 1935 has been awarded to Dr. David Schenck Jacobus, past-president and honorary member, A.S.M.E., for his outstanding leadership in the formulation of codes and procedures which have made fusion welding acceptable.

The Morehead Medal is awarded annually by the International Acetylene Association to

D. S. JACOBUS

the person or persons who, in the judgment of its officers and board of directors, have done most to advance the industry or the art of producing or utilizing calcium carbide or its derivatives. The award was established in 1922 by the Hon. John Motley Morehead, formerly United States Minister to Sweden, in honor of his father, the late James Turner Morehead, who, in 1892, sponsored the experiment which lead to the discovery of the electric-furnace method of producing calcium carbide.

Metropolitan Junior Group Plans Program

REPLIES to a questionnaire sent out in September by the Metropolitan Junior Group of The American Society of Mechanical Engineers have netted so far only a 10 per cent return. The answers already received, however, have provided valuable information on Juniors' interests.

As a result of these replies the program committee now has some fifty suggestions for future programs, as well as several strong leads and offers to provide interesting speakers. The *Queen Mary* and Midtown Tunnel provided the greatest number of suggestions as to objectives for future inspection trips.

Juniors who know of speakers who would interest a group should send the names to the program committee. Any one who wishes to visit some place of engineering interest and has been unable to arrange for it personally may propose it to the Committee, who will make arrangements if possible.

The study groups came in for comments on the returned questionnaires. Interest shown in the engineers' economic advancement study group places it first, while aeronautics and national defense tie for second place.

Five new study groups have been suggested: Sales engineering, internal-combustion engineering, metallography, air conditioning, and human engineering.

The committees of the Metropolitan Junior Group regard the expressions of opinion received as a result of their questionnaire as of prime importance in formulating plans for the future. Members who have not sent in their views are asked to do so immediately. Ideas and suggestions are most earnestly solicited.

W. G. HAUSWIRTH.[1]

D. B. Prentice Honored by Lafayette

AT THE Founders' Day exercises of Lafayette College, Easton, Pa., October 16, Dr. William Mather Lewis conferred the honorary degree of Doctor of Science on Donald B. Prentice, member A.S.M.E., president of Rose Polytechnic Institute. President Prentice is a member of the Committee on Local Sections of The American Society of Mechanical Engineers.

To Represent A.S.M.E. at Rome Educational Congress

PRESIDENT W. L. Batt has appointed Grand Officiale Ing. Pio Perrone, Honorary Member of The American Society of Mechanical Engineers, to serve as honorary vice-president in representing the Society at the International Congress on Technical Education, to be held in Rome, December 28–30, 1936.

[1] Chairman, Publicity Committee, Metropolitan Junior Group, New York, N. Y.

Elihu Thomson Honored

PROF. ELIHU THOMSON, honorary member, A.S.M.E., one of America's greatest pioneers in the field of electrical science and holder of more than 800 patents, was honored on Oct. 16, 1936, when the Detroit section of the American Welding Society dedicated its program to the fiftieth anniversary of one of Professor Thomson's greatest industrial inventions, that of resistance welding.

The basic patent on this method of joining metals by putting them in contact with one another and then passing through them an electric current which fuses and unites the pieces was granted in 1886.

The original welding transformer perfected by Professor Thomson, now the property of

ELIHU THOMSON

the Franklin Institute in Philadelphia, was brought to Detroit. A. L. Rohrer, former electrical superintendent of the General Electric Company, who helped Professor Thomson with the original experiments fifty years ago, spoke from the exact spot where the welding development work took place on the second floor of an old G-E factory building in Lynn, and his voice was carried by wire and reproduced at the meeting by a public-address system.

Professor Thomson's health is such that he was unable to make the trip from his home in Swampscott, Mass., but he sent a special message which his son, Malcolm, read to the society.

Professor Thomson, now in his eighty-fourth year, is one of the cofounders of the General Electric Company. He is the holder of numerous medals and awards and is the only scientist in the world who possesses the three most coveted awards of English scientific and engineering institutions, the Faraday, Kelvin, and Hughes medals.

The President Dedicates the

MEMBERS' PAGE

THIS is the last opportunity I shall have of addressing members of The American Society of Mechanical Engineers by means of the President's Page. I want to use the space allotted to me this month to dedicate a Members' Page—a forum for the discussion of Society affairs.

Every membership organization needs a forum in which personal views can be expressed, criticisms offered, and misunderstandings cleared up.

Members of this Society have always had the privilege of placing their suggestions before the Council, orally or in writing, and, in my judgment, such suggestions have always been given careful consideration. Because the Council has failed to act favorably on a suggestion does not mean that it has failed to give proper heed to it. The Council has merely failed to be convinced. Had the author of the suggestion appealed to his fellow members publicly, through Mechanical Engineering, he might have been able to arouse favorable support for it before presenting it to the Council. And the Council would have had member opinion to assist it in coming to a decision. But in any event, the member could not feel his views had been lightly treated if he had placed them before his fellow members in the publications of the Society.

Because I want to be sure that every member has an opportunity to be heard publicly on matters relating to the Society, I have secured the consent of the Council and the Committee on Publications to establish a members' page in Mechanical Engineering.

I hereby dedicate this page to the members. It is now their privilege and responsibility to make use of it, and I invite them to do so.

To every member, therefore, I say: "This is your page. Make use of it. By means of it place your suggestions and opinions on Society affairs before your fellow members. Discuss the views of others that will be published here. It will help the Council, the officers, and the administrative committees. It will help to build a better Society. It will improve our mutual understanding."

W. L. Batt.

James A. Hall Dies

James A. Hall, manager and vice-president elect of The American Society of Mechanical Engineers and professor of mechanical engineering at Brown University, died at Providence, R. I., on October 29, of thrombosis. Born in Berlin, Vermont, in 1888, he attended the public schools of Providence and was graduated from Brown University in 1908 with the degree of A.B. He received the degree of bachelor of science in mechanical engineering from the same institution in 1910, remaining as assistant and then instructor in mechanical engineering until 1914, when he became connected with the engineering department of the Link-Belt Company in Philadelphia. The following year he returned to Brown University as assistant professor of mechanical engineering, teaching courses in machine design and industrial management. He became associate professor in 1920, and since 1925 has been professor of mechanical engineering. Professor Hall has also carried on a consulting-engineering practice, and since 1926 has been associated with the Brown & Sharpe Manufacturing Company in Providence, R. I., as consulting engineer.

JAMES A. HALL

Professor Hall joined the Society in 1912. He was chairman of the Providence Section of the Society in 1922, and a member of the Committee on Local Sections from 1922 to 1926, being chairman the last year. He was a member of the Research Committee on the Cutting and Forming of Metals from 1924 to 1930, and chairman from 1925 to 1927. He was chairman of the Nominating Committee of the Society in 1929, and a member of the Committee on Constitution and By-Laws 1931 to 1933. In 1933 he was elected manager of the A.S.M.E. and has served on the Executive Committee of the Council of the Society since that time.

At the time of his death he was chairman of the Machine Design Committee of the Society's Machine Shop Practice Division. Professor Hall was a past-president of the Providence Engineering Society, past-chairman of the New England Section of the S.P.E.E., a member of the Newcomen Society, of the Society of Sigma Xi and fellow of the American Association for the Advancement of Science. He was the author of numerous articles published in the technical press.

A.S.M.E. Technical Committees

AFTER a full-day meeting held at A.S.M.E. headquarters on October 26, Melvin D. Engle, chairman, reports the completion of the first draft of the proposed American Standard for Pressure and Vacuum Gages. This was a meeting of the Subcommittee on Plan and Scope whose task was to edit and coordinate into a unified whole the reports of Subcommittees Nos. 2, 3, and 4. Copies of this draft have been submitted to the members of the sectional committee for review.

Graphical Symbols

Dr. Thomas E. French, chairman, presided at the meeting of Subcommittee No. 1 on Graphical Symbols for Use in Mechanical Engineering which was held on the same day. At this time a number of additions were made to the personnel of the subcommittee and two subgroups were appointed. The Subcommittee to Correlate and Revise Symbols of the American Welding Society has been invited to become a subgroup of this subcommittee to develop standards for welding symbols. It was recognized that the A.W.S. committee, by the work it has already done on welding symbols, has laid a foundation for the activity of this subgroup. A subgroup on heating, ventilating, refrigeration, and air-conditioning symbols will use as part of the basis of its work the refrigeration symbols recently adopted by the Refrigerating Machinery Association.

Soldered Fittings

Arthur M. Houser was elected temporary chairman and E. L. Penfrase secretary at the organization meeting on October 29 of Subcommittee No. 11 on Soldered Fittings of Sectional Committee on Minimum Requirements for Plumbing and Standardization of Plumbing Equipment (A40). Extensive plans were made for the future work of this committee and several members were designated as members of subgroups to prepare reports on fitting limits and tolerances, length of joint, laying lengths, etc., for presentation to Subcommittee No. 11 at its next meeting.

Threaded Cast-Iron Pipe and Fittings

Another new subcommittee of Sectional Committee A40 held its organization meeting on October 29. It was Subcommittee No. 10 on Threaded Cast-Iron Pipe and Fittings. F. Hugh Morehead was elected chairman of a subgroup to develop a proposed American Standard for this type of pipe intended for vent, waste, and drainage purposes. The committee is interested as well, however, in the development of specifications for threaded cast-iron pipe for pressure purposes and to this end recommended that a joint conference committee of Sectional Committee A40 and Sectional Committee on Specifications for Cast-Iron Pipe and Special Castings (A21) be appointed to discuss its initiation.

Standardization of Plumbing Equipment

Twenty-six persons attended the meeting of Sectional Committee A40 on Minimum Requirements for Plumbing and Standardization of Plumbing Equipment held in the Engineering Societies Building on October 30. The committee reviewed the status of the work of its many subcommittees and suggested several subjects for investigation by the Research Committee on Plumbing which had held a meeting that morning.

Steel Flanges and Flanged Fittings

Subcommittee No. 3 on Steel Flanges and Flanged Fittings, C. P. Bliss, chairman, worked long and arduously on the afternoon of October 30 in its efforts to complete the task of drafting the proposed revision of the present American Standard for this product, B16e–1932. The meeting which began at 2:00 p.m. did not adjourn until 7:30 p.m. We wish to record, however, that the proposed revision, involving many additions and changes, was completed and will shortly be submitted for approval.

$20,000 Not $15,000

Since the publication of the note in the November issue of MECHANICAL ENGINEERING entitled "Three Research Committees Pass the Hat," page 760, an error has been called to our attention. We announced that the Joint Research Committee on the Effect of Temperature on the Properties of Metals was canvassing for a sum of $15,000, while in reality it has set $20,000 as its goal to cover a three-year program.

Other Engineering Activities

N.C.S.B.E.E. Meets at Knoxville

THE seventeenth annual meeting of the National Council of State Boards of Engineering Examiners was held at Knoxville, Tenn., Oct. 19–21, 1936. The attendance was the largest in the history of the Council, both in number of states represented and in individuals present.

The time was spent principally in the discussion of matters helpful to the various state boards in the improvement of the administration of the state laws for licensing and registration of engineers. The feature of public interest was the annual banquet which was addressed by Arthur E. Morgan, chairman and chief engineer of the Tennessee Valley Authority. He took occasion to emphasize the responsibility of the engineer in society to keep open the road through which there may ar-

rive the great variety of contributions of life that make for a full civilization. He pointed out that the problems of the engineer are not all of precise technique. Many have to do with synthesizing plans and human aspirations.

Officers were elected as follows: president, J. S. Dodds; vice-president, S. H. Graf, member A.S.M.E.; executive secretary, T. Keith Legaré. These officers, with Past-President James L. Ferebee, of Milwaukee, Wis., and the following make up the board of directors: K. C. Wright, Salt Lake City, Utah, R. A. Seaton, Manhattan, Kan., C. L. Mann, Raleigh, N. C., and C. G. Massie, Lynchburg, Va.

Upon the invitation of A. B. Clemens, member, A.S.M.E., and a member of the Pennsylvania State Board, the National Council of State Boards voted to meet in Scranton, Pa., in October, 1937.—C. E. DAVIES.

Welding Society Announces Evening Lecture Course in New York Area

THE New York Section of the American Welding Society has arranged with the Polytechnic Institute of Brooklyn to present this winter a series of lectures on the fundamentals of welding. The lectures will be given in the Institute, 99 Livingston St., Brooklyn, on Tuesday evenings at 6:45, beginning November 10.

The course will comprise ten illustrated talks by well-known authorities. Information on enrolment fee and other particulars may be obtained by addressing the American Welding Society, 33 West 39th St., New York, N. Y.

S.P.E.E. Middle Atlantic Section Meets in New York, December 5

THE Middle Atlantic section of the Society for the Promotion of Engineering Education will meet at Columbia University, Dec. 5, 1936.

Registration, beginning at 9:30 at the Engineering Building, will be followed by tours with guides at 10 a.m. and a luncheon at 12:30.

Technical and business sessions will be held in the Harkness Academic Theater at 2 p.m. Dean J. W. Barker, of Columbia University, will present the greetings of the University. The principal addresses will be delivered by Professors Harry J. Carman and Horace Taylor, of Columbia University, on the humanistic content of engineering curricula, with an example of an integrated program. There will be discussion of the subject by H. S. Rogers; president, Polytechnic Institute of Brooklyn; W. O. Hotchkiss, president, Renssalaer Polytechnic Institute; Harvey N. Davis, president, Stevens Institute of Technology; and H. Diederichs, dean, College of Engineering, Cornell University.

Inspection of the engineering laboratories will follow the addresses which will be delivered in the afternoon.

Dinner will be served at 6:30 at the Mens' Faculty Club, at which Dr. Nicholas Murray Butler, president, Columbia University, Harry P. Hammond, president, S.P.E.E., and James K. Finch, of Columbia University, will speak.

Welding Medal Awarded to Henry Metcalf Hobart

AS "pioneer and leader in a welding research movement which in nineteen years has spread to the far corners of the world and vitally affected industry," Henry Metcalf Hobart, member A.S.M.E., consulting engineer of the General Electric Company, Schenectady, N. Y., was awarded the Samuel Wylie Miller Memorial Medal of the American Welding Society, at its annual meeting, Cleveland, Ohio, October 19, 1936.

H. A. HOBART

Mr. Hobart, chairman of the Fundamental Welding Research Committee of the Engineering Foundation which is directing more than sixty welding researches in university laboratories, reported to the Emergency Fleet Corporation in 1917 a study of the application of welding to shipbuilding in Great Britain. This report marked the beginning of American research which is said to have developed welding into "the most important and most widely used tool of industry."

Welding Society Officers

Alfred E. Gibson, member A.S.M.E., and vice-president of the Wellman Engineering Company, Cleveland, Ohio, has been elected president of the American Welding Society and Edwards R. Fish, member A.S.M.E., of the Hartford Steam Boiler Inspection and Insurance Company, Hartford, Conn., senior vice-president. Other A.S.M.E. members elected to offices in the American Welding Society were John H. Zimmerman, Massachusetts Institute of Technology, regional vice-president; Ira T. Hook, American Brass Company, Ansonia, Conn., director; and H. S. Smith, Union Carbide Company, New York, N. Y., director.

1938 Congress for Applied Mechanics to Be Held at M.I.T.

THE American committee, to whom has been delegated responsibility for organizing the Fifth International Congress for Applied Mechanics by the International Committee at its meeting at Cambridge University, England, in July, 1934, announces that the Fifth Congress will meet in Cambridge, Mass., Sept. 12–16, 1938, at Harvard University and the Massachusetts Institute of Technology. As in the past, this Congress is to be a meeting of persons working in the field of applied mechanics before whom reports of recent work may be presented for discussion.

The program will cover three main divisions of applied mechanics as follows:

(1) Structures, elasticity, plasticity, fatigue, strength theory, crystal structure.

(2) Hydro and aerodynamics, gasdynamics, hydraulics, meteorology, water waves, heat transfer.

(3) Dynamics of solids, vibration and sound, friction and lubrication, wear and seizure.

Following the meeting at Cambridge it is expected that arrangements will be made to visit Washington (National Bureau of Standards), and Langley Field (National Advisory Committee for Aeronautics).

Dormitory and boarding facilities will be made available by Harvard University.

Inquiries should be addressed to the Fifth International Congress for Applied Mechanics, Massachusetts Institute of Technology, Cambridge, Mass.

Secretaries for the American committee are Th. von Kármán, California Institute of Technology, Pasadena, Calif., and J. C. Hunsaker, Massachusetts Institute of Technology, Cambridge, Mass.

United Engineering Trustees Elect Officers

GEORGE L. KNIGHT, member A.S.M.E., vice-president in charge of mechanical operations of the Brooklyn Edison Company, has been reelected president of the United Engineering Trustees, Inc., joint agency of the four Founder Engineering Societies.

Otis E. Hovey, member A.S.M.E., consulting engineer of 71 Broadway, and D. Robert Yarnall, member A.S.M.E., chief engineer of Yarnall-Waring Company, Philadelphia, were named vice-presidents. John H. R. Arms, member A.S.M.E., general manager of the United Engineering Trustees, continues as secretary. Albert Roberts, secretary of the Minerals Separation North America Corporation, New York was reelected treasurer.

H. R. Woodrow, vice-president in charge of electrical operations of the Brooklyn Edison Company, was chosen assistant treasurer.

The following trustees were chosen: Henry A. Lardner, member A S.M.E., of J. G. White Engineering Corporation; John P. Hogan, member A.S.M.E., of Parsons, Klapp, Brinckerhoff, and Douglas, New York; Mr. Yarnall and Mr. Woodrow. Other trustees are H. P. Charlesworth, assistant chief engineer, American Telephone and Telegraph Company; J. P. H. Perry, vice-president, Turner Construction Company, New York; A. L. J. Queneau, United States Steel Corporation, New York; Walter Rautenstrauch, member A.S.M.E., professor of industrial engineering, Columbia University.

Engineering Foundation Elects Officers

ELECTION of Frank Malcolm Farmer, member A.S.M.E. and vice-president and chief engineer of the Electrical Testing Laboratories, New York, N. Y., as chairman of the Engineering Foundation, research organization of the national engineering societies, is announced.

D. Robert Yarnall of the Yarnall-Waring Company, Philadelphia, Pa., member A.S.M.E., was relected vice-chairman of the Foundation. Alfred D. Flinn continues as director and secretary.

Elected to the executive committee were Otis E. Hovey, member A.S.M.E., New York; A. L. J. Queneau, metallurgist of the United States Steel Corporation, New York; and Walter I. Slichter, member A.S.M.E., of Columbia University.

Mr. Yarnall was chosen chairman of the Foundation's research procedure committee, other members of which were named as follows:

Frederick M. Becket, vice-president of the Electrometallurgical Company, New York; Thaddeus Merriman of 380 Riverside Drive, New York, representing the American Society of Civil Engineers; Walter H. Fulweiler of Wallingford, Pa., representing The American Society of Mechanical Engineers; Lewis W. Chubb, director of the Westinghouse Research Laboratories, East Pittsburgh, Pa., representing the American Institute of Electrical Engineers; Sam Tour of 47 Fulton Street, New York, representing the American Institute of Mining and Metallurgical Engineers; Alfred D. Flinn, secretary.

The Foundation's Iron Alloys Committee, which is directing a critical review of the world's knowledge of steel, alloy steel, alloy iron, cast, wrought, and pure iron, will be composed of:

George B. Waterhouse, of Massachusetts Institute of Technology, chairman; J. G. Thompson, chief of the section on chemical metallurgy, National Bureau of Standards, representing Lyman J. Briggs, director of the Bureau; John W. Finch, director, and Reginald S. Dean, chief engineer, of the metallurgical division, U. S. Bureau of Mines; James T. MacKenzie, metallurgist and chief chemist of the American Cast Iron Pipe Company, Birmingham, Ala.; John Johnston, director of research of the U. S. Steel Corporation, Kearny, N. J.; Dean Bradley Stoughton, of Lehigh University; Jerome Strauss, vice-president of the Vanadium Corporation of America, Bridgeville, Pa.; Thomas H. Wickenden, member A.S.M.E., metallurgical engineer of the International Nickel Company, New York; James H. Critchett, vice-president of Union Carbide and Carbon Research Laboratories, New York; Wilfred Sykes, director of the Inland Steel Company, Chicago; Frank T. Sisco of New York, editor.

The Welding Research Committee, sponsoring investigations in university and industrial laboratories, and compiling a survey of the welding practice and theory of all nations, will include:

Comfort A. Adams, member A.S.M.E., and director of the American Bureau of Welding, chairman; D. S. Jacobus, past-president A.S.M.E., Babcock and Wilcox Company, New York; Henry M. Hobart, member A.S.M.E., General Electric Company, Schenectady; Mr. Critchett; Frederick T. Llewellyn, of the U. S. Steel Corporation, New York; Col. Glen F. Jenks, member A.S M.E., commanding officer of the Watertown (Mass.) arsenal; John J. Crowe, of the Air Reduction Sales Company, Jersey City, N. J.; C. L. Eksergian, member A.S.M.E., Budd Wheel Company, Detroit; William Spraragen of New York, secretary.

Additional members of the committee will be designated to represent the railroad, public utility, nonferrous metals, automotive and aircraft, shipbuilding, and oil industries, and electric-welding-apparatus manufacturers, resistance-welding manufacturers, machinery manufacturers, and structural-steel fabricators.

With the Student Branches

Student Branch Doings

WHEN you conduct a student-branch meeting, everything is run according to rules and regulations. Publications must observe the same principles. Therefore, if you desire to see the news about your branch and members printed, you must observe the cardinal principle of writing, make it interesting, not only to yourselves but to others who might read it. With 114 other student branches to compete against for the limited space available to us, each branch must and should make their reports to the Secretary of the Society superinteresting. It is from these reports that we glean the little articles which we print here.

Going through the reports since the beginning of the term, it is observed that many branches are breaking all attendance records at their sessions. How? By conducting interesting meetings. Here's a list of branches who had fifty or more professors, regular, and prospective members at one of their meetings:

Michigan	200	Brooklyn Poly	58
Wisconsin	150	California Tech	55
Newark	95	Michigan State	55
Armour	78	Nebraska	51
Pennsylvania	75	Lewis Institute	50
Drexel	68	Notre Dame	50
Case	60	George Washington	50

Some of the branches elected officers for the coming semester at their first meeting. Following is a list of those who attained these important positions in their respective branches. . . . . . COLORADO, David H. Ware, Donald R. Metzger, William Worthington, and Donald Risley. . . . . .CARNEGIE, Raymond Reisacher, Homer Jones, B. Gebhart, and W. L. Lowry. . . . . .OHIO NORTHERN, R. H. Leisenheimer, T. Baker, E. I. Salo, and S. C. Stayer. . . . . .WASHINGTON STATE, Everett Hanson, Marvin Swerson, William Cartwright, and Henry Brunelle.

VERMONT reports that all eligible members have signed up thus giving them a 100 per cent membership record. . . . . .MISSOURI changed its by-laws so as to allow freshmen and sophomores who do not want to become regular members to be associate-members upon the payment of fifty cents per semester to the branch. . . . . .NEWARK meetings for the coming year include the following subjects: Fuels, automotive advancement, aeronautics, steam power, internal-combustion engines, heating and ventilation, aviation landing-field maintenance, automotive industry, transporta-

Professor H. F. Godeke, left, professor of mechanical engineering and honorary chairman of the Student Branch of the A.S.M.E. at Texas Technological College, Lubbock, Texas, shakes hands with Al Ray Cooper, senior student in Mechanical Engineering and newly elected president of the Branch.

tion, and metals. . . . . . SOUTH DAKOTA STATE at its first meeting had all old and prospective members stand up and introduce themselves to the audience. 'Tis a very good idea which creates friendship and good fellowship. . . . . . VIRGINIA POLY intends to run meetings in the form of short debates by the members themselves on engineering and related subjects. Some of the topics to be selected are hydraulic versus mechanical brakes, lighter-than-air versus heavier-than-air airships, etc.

Some of the branches have been conducting some worth-while trips during the last few months. We find that WEST VIRGINIA inspected the Tygart River Dam and Reservoir, LOUISIANA STATE members went on board a modern dredge boat somewhere on the Atchafalaya River, COLORADO STATE visited a sugar-refining plant, NEBRASKA went over the Union Pacific Railroad's shops, STEVENS saw how radio tubes are made in the RCA Radiatron plant, ARMOUR was the guest of the Northwestern Railroad on an inspection through its shops and power plant, CCNY visited local central power stations in New York City, RICE went in for textile factories, and NOTRE DAME watched the processes in a rubber factory. Up to now none of the branches have visited any breweries.

In a talk given before the members of the CASE Branch, J. A. Hunter, professor emeritus of mechanical engineering at the University of Colorado and vice-president of the Society said, "The way you comb your hair has a lot to do with your future success. Good grades will get you places, but they don't mean everything. It is just as important to make of yourselves men who will be respected. Study how to improve your personality and appearance. If you neglect yourself, you are going to be the sufferer."

LESLIE F. ZSUFFA.[1]

Student Members Attend Junior Dinner

Membership Subcommittee Formed

THE A.S.M.E. Junior Group dinner to Metropolitan student-branch representatives was held in the Terra Cotta room of the Hotel Dixie, New York, on Wednesday, October 21.

Honorary chairmen and officers of the class of 1936 from Columbia, New York University, Stevens Institute of Technology, Pratt Institute, Cooper Union, Polytechnic Institute of Brooklyn, College of the City of New York, and Newark College of Engineering were guests of the Junior Group. Arrangements for the dinner and program of the evening were made by the membership committee of the juniors, Walter W. Lawrence chairman.

The dinner was attended by some ninety persons, comprising a score of juniors, the heads of the engineering departments of several of the colleges, and the invited guests of the class of 1936. Immediately after dinner, toastmaster Lawrence presented the speakers of the evening.

[1] Member, Editorial Board for Student Branch News. Jun. A.S.M.E.

By prearrangement, Roy V. Wright and J. N. Landis, representing the senior members, and O. B. Schier, chairman of the Junior Group spoke briefly and informally on the relations of the newly graduated engineer to the Society and to the Junior Group.

The average student upon graduation finds himself suddenly outside the sanctuary of the college campus. On him rests the decision of joining an engineering society made up of men who are older, more experienced, and entirely unknown to him.

As an aid to the graduated student at this crossroads of his professional life, it is planned to create a committee of the leaders of the graduates of that year. This committee will be composed of men like himself, just recently graduated, and having interests which are no longer entirely collegiate, yet somewhat uncertain as to the future.

Through this subcommittee of the Junior Group membership committee it is hoped to establish a closer tie between student members in the schools and junior members of The American Society of Mechanical Engineers. —W. G. HAUSWIRTH.[2]

[2] Chairman, Junior Group Publicity Committee, A.S.M.E. Metropolitan Section.

Dedication of Ferris Hall, University of Tennessee

ON October 24, 1936, Ferris Hall, housing the administration offices of the Engineering College and the Departments of Electrical Engineering and Hydraulic Engineering, at the University of Tennessee, Knoxville, Tenn., was dedicated with appropriate ceremonies.

Dean Charles E. Ferris, member A.S.M.E., for whom the building was named, has been a member of the faculty of the University of Tennessee for 45 years and Dean of Engineering for 33 years.

Dean Ferris has been a prominent figure in engineering education, and is still active as Dean of Engineering and as an outstanding teacher of thermodynamics.

Sharing the honors with Dean Ferris at the dedication ceremonies was Dr. Charles A. Perkins, professor of electrical engineering, who came to the University of Tennessee 45 years ago. Dr. Perkins retired in 1929 as head of the department of electrical engineering and since that time has been active as director of the engineering experiment station and professor of electrical engineering.

The outstanding feature of the dedication program was the presentation and unveiling of busts of Dean Ferris and Dr. Perkins. The busts were the gift of engineering alumni of the university and were the work of Gilbert Switzer of Philadelphia. Mr. Switzer is a former student of the university and a son of Prof. and Mrs. John A. Switzer of the University of Tennessee. Professor Switzer is a member of The American Society of Mechanical Engineers.

Major Thomas H. Allen, class of 1903, made the dedicatory address, and the busts were presented by John B. Cox, B.S. in M.E., 1893, on behalf of the engineering alumni. Mrs. Switzer, mother of the sculptor, unveiled the busts.

The busts of Dean Ferris and Dr. Perkins will be given a place of prominence in Ferris Hall. Ferris Hall is the main building of a future building program which is to include new wings housing the mechanical-, civil-, and chemical-engineering departments.

The News From Washington

By American Engineering Council

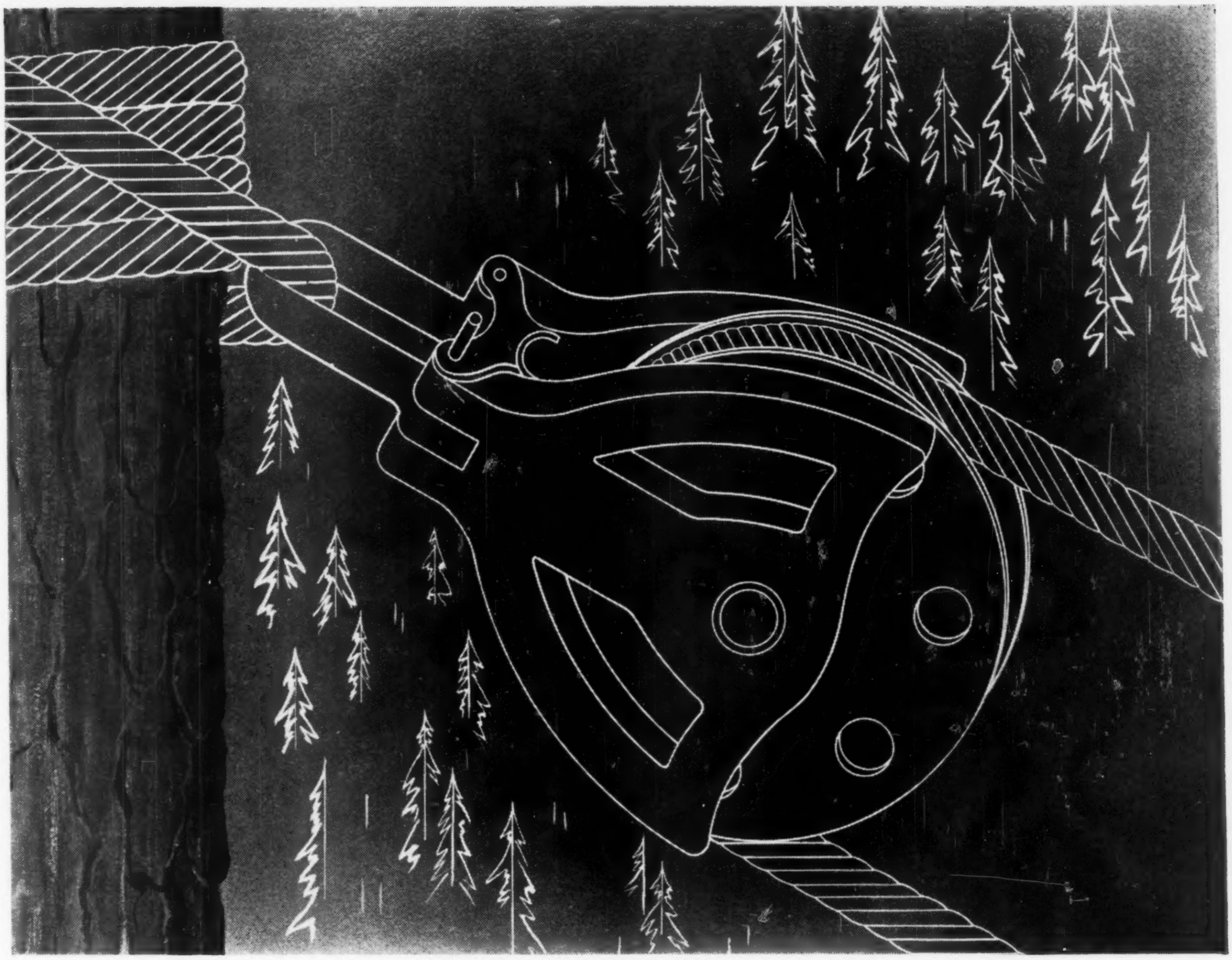
THE November news letter of the American Engineering Council contained the following comment of interest to mechanical engineers.

Rural Electrification Administration's current releases show a material acceleration in loans to both the publicly owned light and power cooperatives and privately owned light and power utilities engaged in rural electrification. Invitations to bid on such work and actual construction are keeping pace with the loan situation. On Oct. 30, 1936, the REA reported that it had lent or definitely earmarked a total of $35,728,178 to build about 32,000 miles of rural electric lines to serve over 120,000 customers with either privately or publicly owned central-station electricity. Administrator Morris L. Cooke reported that nearly 1500 miles of rural electric lines have been energized and that 4200 farm families are already using electricity for the first time. Although loan contracts between the Electric Home and Farm Authority and public and private utilities are not reported to be keeping up with Rural Electrification Administration activities, they are rapidly becoming effective in the communities which are accepting rural electrification.

SEC Reports

Securities and Exchange Commission reports registrations of securities amounting to $3,573,973,000 for the first nine months of 1936 in comparision with $1,769,750,000 for the same period in 1935. These figures do not include amounts registered exclusively in connection with plans for companies in reorganization or in connection with the issuance of certificates of deposit and voting trust certificates. The figures, however, include such amounts as represent securities which, although registered, were intended for purposes other than immediate cash sale. Utility companies were the largest registers of securities.

(A.S.M.E. News continued on page 862)



Financial and investment companies were second, and manufacturing companies were third in size. The main use proposed to be made of these funds was the repayment of indebtedness. The next largest use was for working capital, including funds for finance companies. The third largest was proposed for the purchase of securities by investment companies. The fourth (6.6 per cent) was the financing of plant, equipment, and real estate. Practically all the remainder was scheduled for payment of bonds and notes before maturity.

Bureau of Mines Reorganization

Bureau of Mines reports the appointment of Arno C. Fieldner as chief of the Technologic Branch of the United States Bureau of Mines. Coincident with the appointment of Mr. Fieldner, the Bureau of Mines has had considerable reorganization. The Mechanical Division is changed to the Coal Division and studies relating to the use of electrical and mechanical equipment in mining are transferred to the Mining Division. The Experimental Station Division has been discontinued, and the Coal Preparation Section and Experimental Mining Section have been transferred to the Coal Division. A new Nonmetals Division has been created to take over the technical sections of discontinued experimental stations.

Developments in Public Roads

Bureau of Public Roads' summary for the year ending June 30, 1936, shows contracts awarded for 22,300 miles, at a cost of $489,000,000, of which $393,000,000 was to be supplied by Federal Government agencies. Work actually under construction totalled 21,800 miles, at a total cost of $454,000,000, of which the cost to the federal government is to be $369,000,000. The 17,300 miles of road completed were built at a total cost of $280,000,000, including $241,000,000 in federal funds. During the fiscal year, 300 railroad grade crossings were eliminated, 18 temporary elimination structures were reconstructed and protective devices were installed at 185 crossings. At the end of the year, 1240 eliminations were under contract—most of them under construction—and 168 elimination structures were under contract for reconstruction. Over $500,000,000 was allocated from the Emergency Relief Appropriation Act of 1935 for such work. Directly and indirectly, highway work administered by the Bureau is said to have supported more than one million people.

A recent report by the Bureau states that highways are now being designed for the safe accommodation of vehicles moving at rates of speed up to 60 miles. This applies to new highways and to the improvement of a large mileage of the older highways being undertaken by successive stages.

CCC Junior Assistants

Civilian Conservation Corps announced Executive Order 7195 on October 29, providing for one junior assistant to the Chief Technician in each camp—a newly created civil-service job, open only to Civilian Conservation Corps enrollees. In anticipation of such opportunities, the Civil Service Commission conducted competitive examinations in CCC camps last summer and approximately 15,000 enrollees were found eligible. The position pays $85 per month and successful candidates must resign as enrolled men and become members of their camp supervisory or administrative forces. The junior assistants will carry on their duties under the direct supervision of skilled technical men, including graduate engineers, foresters, architects, and other technicians supervising the camp work program.

Flood-Control Studies

Works Progress Administration has allotted $5,500,000 to the Engineer Corps of the Army to cover the cost of making flood-control studies, authorized by the last Congress. The appropriation which Congress intended to make, died in the hectic hours of the last Session. Being work-relief funds, the WPA allotment carries relief restrictions to employment and compensation, which lead to difficulties in the mobilization of engineering forces. The only exemption obtained to date permits the employment of engineers on flood-control studies for 130 hours per month at prevailing wages. Prevailing wages in this instance is interpreted as being the same as those paid under civil service for comparable performance.

The Army's efforts to put this program into execution are creating a great many opportunities for engineers to work, but unfortunately the relief restrictions keep most of them in the subprofessional classification. In other words, present interpretations of the law enacted by Congress forbid the use of the funds made available for the employment of all people except those who are out of work or forced to accept relief work. As a result of the confusion, competition is developing among emergency agencies using relief funds, and state administrators of the Works Progress Administration are being urged to abandon the less essential projects and allow the transfer of technically trained employees to flood-control survey units of the Engineers' Corps of the Army.

PWA Projects

Public Works Administration releases for October carry an announcement of new loans and grants on several hundred projects in thirty-odd states. Allotments have been made since July 1 on more than 1500 projects, estimated to cost $234,957,909. Of this amount, federal grants amount to $105,667,391, and loans $10,836,000. Subtracted from the $300,000,000 made available for Public Works Administration grants and loans by the last session of Congress, these relatively large figures leave almost $200,000,000 available for future loans and grants to political subdivisions willing to provide 45 per cent of the cost of public works.

Only 6.25 per cent of current grants by the Public Works Administration involve loans in comparison with almost 50 per cent on earlier allotments. This change is said to be due to the fact that applicants have discovered that it is to their advantage to sell their securities to private investors, offering higher rates of interest than the Public Works Administration. Secretary Ickes reports that $173,634,105 worth of such securities have been withdrawn by communities who have decided to finance themselves.

The current issue of the Bureau of Labor Statistics shows that 65 per cent of the total disbursements on construction projects went for materials and 35 per cent for labor on the site. Although the analysis is not yet complete, it is expected to definitely determine for the first time the ratio between direct and indirect employment on public works or the relationship between the work generated in producing and transporting materials and that actually done on the building sites. The advance figures show increases in industrial employment ranging from 14.2 per cent to as much as 225.4 per cent for the life of the Public Works Administration. The study goes into considerable detail and breaks the analysis down into individual industries, and may be ready for distribution in the early part of 1937.

Engineering-Employment Situation

The President's Committee on Government Reorganization seems to be concentrating its efforts on a confidential study of Government management and personnel problems, leading to a complete reorganization of the system in which government servants are recruited, promoted, demoted, pensioned, or eliminated from the service. Confidential personal reports to the President are said to carry recommendations for the establishment of a "career service" to take the place of the present mixture of civil service and emergency and unclassified employees depending upon patronage. It is rumored that the career service would be patterned after the "British career system." Such a system would include administrative, professional, clerical, skilled, semiskilled, and unskilled employees, and would determine the proper classification in individual cases by examinations for each category. The plan suggested provides that new employees would undergo a period of probation, after which they would become members of the career service, removable only for cause. Vacancies in the better jobs would be filled by promotions from the lower classifications on the basis of capabilities.

Council's staff is checking the reported recommendations of the President's Committee with reference to both content and seriousness. As soon as the real intent of the report can be determined, our organization will exert its full influence for a merit system free from social and political control and bias.

AEC Annual Meeting

The seventeenth annual meeting of the American Engineering Council and the seventh conference of engineering societies secretaries will take place in January. A special committee of secretaries is arranging an unusually interesting schedule of sessions for the Secretaries' Conference on January 14, and the meetings of Council's Assembly on January 15 and 16 are being arranged to bring the opinions of committees and representatives of member organizations to bear upon problems of most concern to the engineering profession and the public welfare. An All-Engineers' Dinner is planned for the evening of January 15.

(*A.S.M.E. News continued on page 864*)

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Local Sections

Coming Meetings

Akron-Canton: December 18. Dinner at 6:30 p.m. Lecture at 7:30 p.m. at the Y. M. C. A., Akron, Ohio. Subject: "Wire," by a member of the staff of the Bethlehem Steel Company.

Cleveland: December 10. Hotel Statler, at 8:00 p.m. Subject: "Modern Trends in Municipal Government," by Harold H. Burton, Mayor of Cleveland.

Erie: February 16, 1937. Pennsylvania Telephone Building, Erie, Pa., at 8:00 p.m. Subject: "Turbine Locomotives," by B. S. Cain, mechanical designing engineer, General Electric Co., Erie, Pa. Mr. Cain is also Chairman of the Erie Section this year.

Florida: December 28–29, Miami, Fla. The Section will hold a joint meeting with the A.I.E.E. to include interesting technical program, luncheon, and get-together. All members of the Society visiting in Florida at that time are cordially invited.

Indianapolis: December 4. Meeting at Anderson, Ind., at 8:00 p.m. William A. Hanley, formerly Vice-President of the A.S.M.E. will address the members of the Section.

Ontario: December 10. Oak Room, Union Station, Toronto, Ont., Can. at 8:00 p.m. Subject: "Mechanical Applications of the Photoelectric Cell," by George Turnbull, Engineer, Canadian General Electric Co., Ltd.

Philadelphia: December 8. Engineers' Club, 1317 Spruce St., Philadelphia, Pa. Annual Midwinter Frolic.

San Francisco: December 10. 205 Sansome Street, San Francisco, Calif., at 7:20 p.m. Subjects: "High-Speed Prime Movers for Military Transportation," by Capt. B. W. Boyes; "Mechanical Engineering with Relation to Shore Establishments," by Captain W. H. Allen, Civil Engineer Corps.

Schenectady: December 10. Rice Hall, General Electric Co., Schenectady, N. Y. Subject: "Highlights of the State Planning Departments," by W. D. Heydecker, director. New York State Planning Board.

December 17. Junior discussion meeting, Subject: "The Government and Business."

Washington, D. C.: December 10. Potomac Electric Power Co. Auditorium at 8:00 p.m. Subject: "Design Characteristics and Application of Fans," by Harold F. Hagen, vice-president, in charge of research, B. F. Sturtevant Company.

Candidates for Membership in the A.S.M.E.

THE application of each of the candidates listed below is to be voted on after December 26, 1936, provided no objection thereto is made before that date, and provided satisfactory replies have been received from the required number of references. Any member having comments or objections should write to the secretary of the A.S.M.E. at once.

NEW APPLICATIONS

Anderson, Melvin T., Muncie, Ind.
Arnt, Alexander M., Chicago, Ill.
Atkinson, Robt. T., Woodside, L. I., N. Y.
Bass, Russell B., Waterbury, Conn.
Beltran, Edw. V., Brooklyn, N. Y.
Burke, Norman, London, England
Coley, Donald W., Nutley, N. J.
Conviser, M. B., Kingsport, Tenn. (Rt & T)
Dennis, Edwin L., Reserve, La.
Duvall, Wm. G., Baltimore, Md.
Elledge, E. A., Baltimore, Md.
Gray, R. C., Albany, Calif.
Guenther, E. G., Kingsport, Tenn.
Hamilton, Geo. S., Forest Hills, L. I., N. Y.
Hammett, U. R., San Marino, Calif.
Harvey, John F., Barberton, Ohio
Hazen, F. DeF., Pittsburgh, Pa.
Jacobson, Carl A., Beloit, Wis.
Karl, Wm. F., Brooklyn, N. Y.
Keller, Henry G., Glenside, Pa. (Rt & T)
Kipp, H. L., Lawrence, Kan.
Leighton, Albert E., Kingsport, Tenn.
Lewin, P. O., Fall River, Mass.
McCaleb, E. F., Erie, Pa.
Meiere, Jos. W., Kingsport, Tenn.
Nevells, Irving L., Media, Pa.
Rader, Reginald, East Orange, N. J.
Ramberg, Walter, Washington, D. C.
Raynor, Maj. S. N., Philadelphia, Pa.
Reed, Hudson W., Philadelphia, Pa. (Rt & T)
Robinson, Curville J., New York, N. Y. (Re)
Sallmann, Gerard, Cambridge, Mass.
Schabtach, Carl, Scotia, N. Y.
Sills, Titus O., Kannapolis, N. C.
Silva, Renato, Chuquicamata, Chile, S. A.
Smith, Aubrey Lamar, San Francisco, Calif.
Speirs, Geo. W., St. Albans, L. I., N. Y.
Suarez, Louis, Brooklyn, N. Y.
Vaia, Geo. F., Washington, D. C.
Vaughan, Jas. W., Jr., Greenville, S. C.
Wall, Stanley, Charleston, W. Va.
Warren, Wm., Roxboro, N. C.
Wehrmann, Wilhelm, Long Island City, N. Y.
Weir, A. D., Dallas, Tex. (Re)
Weston, Carl A., Charlotte, N. C.
Williamson, Frank A., Glendale, Calif.
Wisch, Herman M., New York, N. Y.
Wohrley, J. R., New York, N. Y.

CHANGE OF GRADING

Transfers from Member

Ryan, Wm. F., Boston, Mass.
Smith, Chetwood, Worcester, Mass.

Transfers from Junior

Atkins, Leland G., Charlotte, N. C.
Bunting, Prof. J. W., Cincinnati, Ohio
Cerny, Walter J., West Hollywood, Calif.
Chapman, A. H., Osborne, S. Australia
Di Santo, Bartel John, Woodbridge, N. J.
Drypolcher, Wm., New York, N. Y.
Durbin, Paul C., New York, N. Y.
Eckhardt, Prof. Carl J., Jr., Austin, Tex.
Hunter, Edgar L., Knoxville, Tenn.
Kinter, Dean W., San Francisco, Calif.
Phinney, R. E., Chicago, Ill.
Piazzoli, Louis P., Jr., Connellsville, Pa.
Ramm, H. F., Bristol, Conn.
Rao, K. N., Hindupur, South India
Winzenburger, Prof. Ernst A., Poultney, Vt.
Zuberbuhler, P., Berne, Switzerland

A.S.M.E. Transactions for November, 1936

THE November, 1936, issue of the Transactions of the A.S.M.E. contains the following papers:

Square-Edged Inlet and Discharge Orifices for Measuring Air Volumes in the Testing of Fans and Blowers (AER-58-7), by L. S. Marks

Undercooling in Steam Nozzles (FSP-58-6), by J. T. Rettaliata

Turbine Supervisory Instruments and Records (FSP-58-7), by J. L. Roberts and C. D. Greentree

Superposed-Turbine Regulation Problem (FSP-58-8), by A. F. Schwendner and A. A. Luoma

Supervising Instruments for the 165,000-Kw Turbine at the Richmond Station (FSP-58-9), by H. Steen-Johnsen

Tests of a 50,000-Sq Ft Surface Condenser at Widely Varying Temperatures, Velocities of Inlet Water, and Loads (FSP-58-10), by G. H. Van Hengel

Physical-Property Uniformity in Valve-Body Steel Castings (FSP-58-11), by A. E. White, C. L. Clark, and Sabin Crocker

Experimental Determinations of the Flow Characteristics in the Volutes of Centrifugal Pumps (HYD-58-4), by R. C. Binder and R. T. Knapp

The Hydraulic-Machinery Laboratory at California Institute of Technology (HYD-58-5), by R. T. Knapp

The Effect of Installation on the Coefficients of Venturi Meters (HYD-58-6), by W. S. Pardoe

A Study of Cutting Fluids Applied to the Turning of Monel Metal (MSP-58-10), by O. W. Boston and W. W. Gilbert

Comparative Torque and Horsepower Requirements of Standard Four-Flute and Spiral-Flute Taps (MSP-58-11), by H. L. Daasch

Coal Washing and the Baum Jig (MH-58-1), by G. L. Arms

Coal Preparation by the Air-Sand Process (MH-58-2), by Thomas Fraser

The Rheolaveur Coal-Cleaning Process (MH-58-3), by John Griffen

A Theory of Paper Drying (PRO-58-6), by E. Cowan and B. Cowan

The Thermal Conductivity of Liquids (PRO-58-7), by J. F. Downie Smith

The Use of Alloy Steels for Side Frames and Bolsters of Freight-Car Trucks (RR-58-3), by D. S. Barrows

The Interpretation of Creep Tests for Machine Design (RP-58-15), by C. R. Soderberg

The Creep Curve and Stability of Steels at Constant Stress and Temperature (RP-58-16), by S. H. Weaver

MECHANICAL ENGINEERING, December, 1936. Vol. 58, No. 12. Published monthly by The American Society of Mechanical Engineers. Publication office at 20th and Northampton Sts. Easton, Pa. Editorial and Advertising departments at the headquarters of the Society, 29 W. 39th St., New York, N. Y. Price 60c a copy, $5.00 a year; to members and affiliates, 50c a copy. $4.00 a year. Postage to Canada, 75c additional, to foreign countries, $1.50 additional. Entered as second-class matter at the Post Office at Easton, Pa., under the Act of March 3, 1879 . . Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on January 17, 1921.

SYMPOSIUM ON CORROSION-RESISTANT METALS IN DESIGN OF MACHINERY AND EQUIPMENT

A.S.M.E. ANNUAL MEETING
DECEMBER 3, 1936

The symposium of the A.S.M.E. on Corrosion-Resistant Metals presents an unusual opportunity to those in industry, especially engineers engaged in design, construction and operation of machinery and equipment, to take a one day course on corrosion under the guidance of a group of cooperating authors who are thoroughly familiar with it.

The problem of corrosion of metals is as old as the metals themselves. It is a universal problem and no respecter of persons, for it is difficult to name an industry using metal in which corrosion of some kind is not a problem. It is a vital problem not only for industry but from the standpoint of the welfare of the nation, for the yearly toll taken by corrosion is stated in astronomical figures. Why should this age-old problem be such a live one today? Technical knowledge in many lines has made more rapid advancement in the past twenty or thirty years than was previously made in many centuries. Our knowledge of corrosion can be classified in this group. The problem has been studied by the chemist, metallurgist, physicist and engineer; its underlying laws and its mechanism are better understood; it can be classified into types; ingenious methods have been developed for its prevention, or for the slowing down of its rate, and new metals have been developed better to resist it.

This new information on corrosion is timely, for processes are being speeded up, which calls usually for higher temperatures and pressures. New chemical substances are being produced, presenting new problems. As in many other lines, the literature on this subject is so voluminous and varied that it is difficult for anyone but a specialist to keep fully informed. The subject is so broad that in the time available only certain high spots can be approached, but the discussion period will offer an opportunity to bring up questions on more specific problems and discussion of other materials which are not covered in the formal papers.

One of the first problems confronted by early civilization was that of wresting from their natural ores the metals used by mankind. With the use of these metals the problem of corrosion was first confronted and continues with us to this day. It is a constant battle against the forces of nature to circumvent the tendency of metals to return to their natural state.

Thos. H. Wickenden

Thomas H. Wickenden, Chairman
A.S.M.E. Committee Corrosion-Resistant Metals Symposium

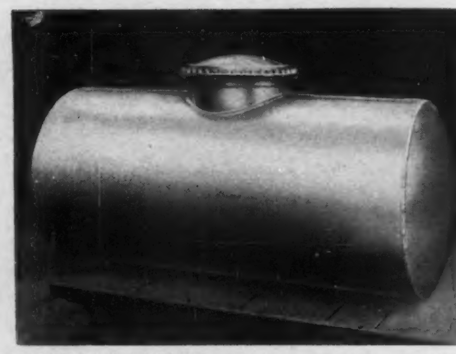
Cut THE COST OF

with

SHAVING CREAM—*Mixing vat of Lukens Nickel-Clad Steel for making shaving cream, built by Curran Boiler Works, Paterson, N. J., for Houchin Machinery Co., Hawthorne, N. J.*

SEWAGE—*Trough of Lukens Nickel-Clad Steel, used for over two years by the Milwaukee Sewage Commission to convey ferric-chloride-treated sludge*

THORIUM SALTS—*Thorium salts are roasted at a temperature of 950° F. in this rotating furnace of Lukens Nickel-Clad Steel, installed at Heyden Chemical Corp., Fords, N. J.*

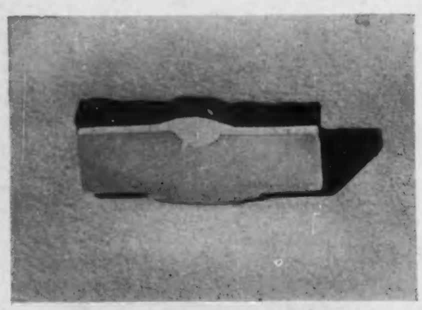


MINERAL WATER—*Pressure tank of Lukens Nickel-Clad Steel, handling mineral waters at Excelsior Springs, Mo., fabricated by American Steel Works, Kansas City, Mo.*

PROOF OF THE STRENGTH, DUCTILITY AND WELDABILITY OF LUKENS NICKEL-CLAD STEEL

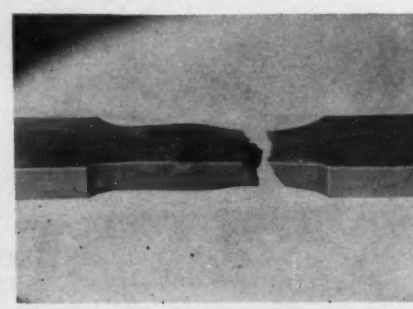
30% ELONGATION WITH NICKEL ON THE OUTSIDE

This standard bend test specimen, ⅝" thick, of Lukens Nickel-Clad Steel, 10% clad on one surface, was cold bent at the weld to 180°, with the Nickel-Cladding and the Nickel weld on the outside. Measured in 2" on the outer fibers across the weld, elongation was 30%, without failure. The photograph of this bend test, illustrated above, is proof of the ductility of Nickel welds in Lukens Nickel-Clad Steel.



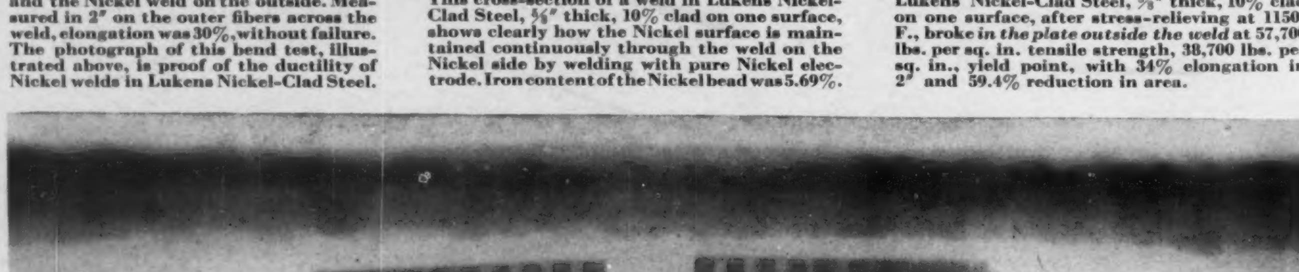
NICKEL'S CORROSION-RESISTANCE COMPLETE IN CLADDING AND WELD!

This cross-section of a weld in Lukens Nickel-Clad Steel, ⅝" thick, 10% clad on one surface, shows clearly how the Nickel surface is maintained continuously through the weld on the Nickel side by welding with pure Nickel electrode. Iron content of the Nickel bead was 5.69%.



STRESS-RELIEVED, REDUCED SECTION TENSILE BREAKS IN PLATE OUTSIDE OF WELD AT 57,700 LBS. P.S.I.

This standard reduced tensile specimen of Lukens Nickel-Clad Steel, ⅝" thick, 10% clad on one surface, after stress-relieving at 1150° F., broke *in the plate outside the weld* at 57,700 lbs. per sq. in. tensile strength, 38,700 lbs. per sq. in., yield point, with 34% elongation in 2" and 59.4% reduction in area.



SOUND WELDS WITH COMPLETE FUSION!

This x-ray of a weld in Lukens Nickel-Clad Steel, ⅝" thick, 10% clad on one surface, shows the soundness of the finished welded joint. Note the complete fusion, and the absence of porosity in the Nickel weld on the clad side and in the steel weld on the steel side.

SENT ON REQUEST...

Up-to-date information on these Anaconda Metals

We have booklets on the following products that contain important data for the engineer. Write for those in which you have immediate interest.

...BERYLLIUM COPPER

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(Everdur, Tempaloy, Benedict Nickel, Ambrac)

...CONDENSER TUBES
(referring specifically to Ambraloy, Super-Nickel, Cupro Nickel and Admiralty)

...EVERDUR METAL

...EVERDUR TANKS

...PIPE AND TUBE
(referring specifically to Anaconda "85" Red-Brass and Copper)

...TOBIN BRONZE

...WELDING RODS

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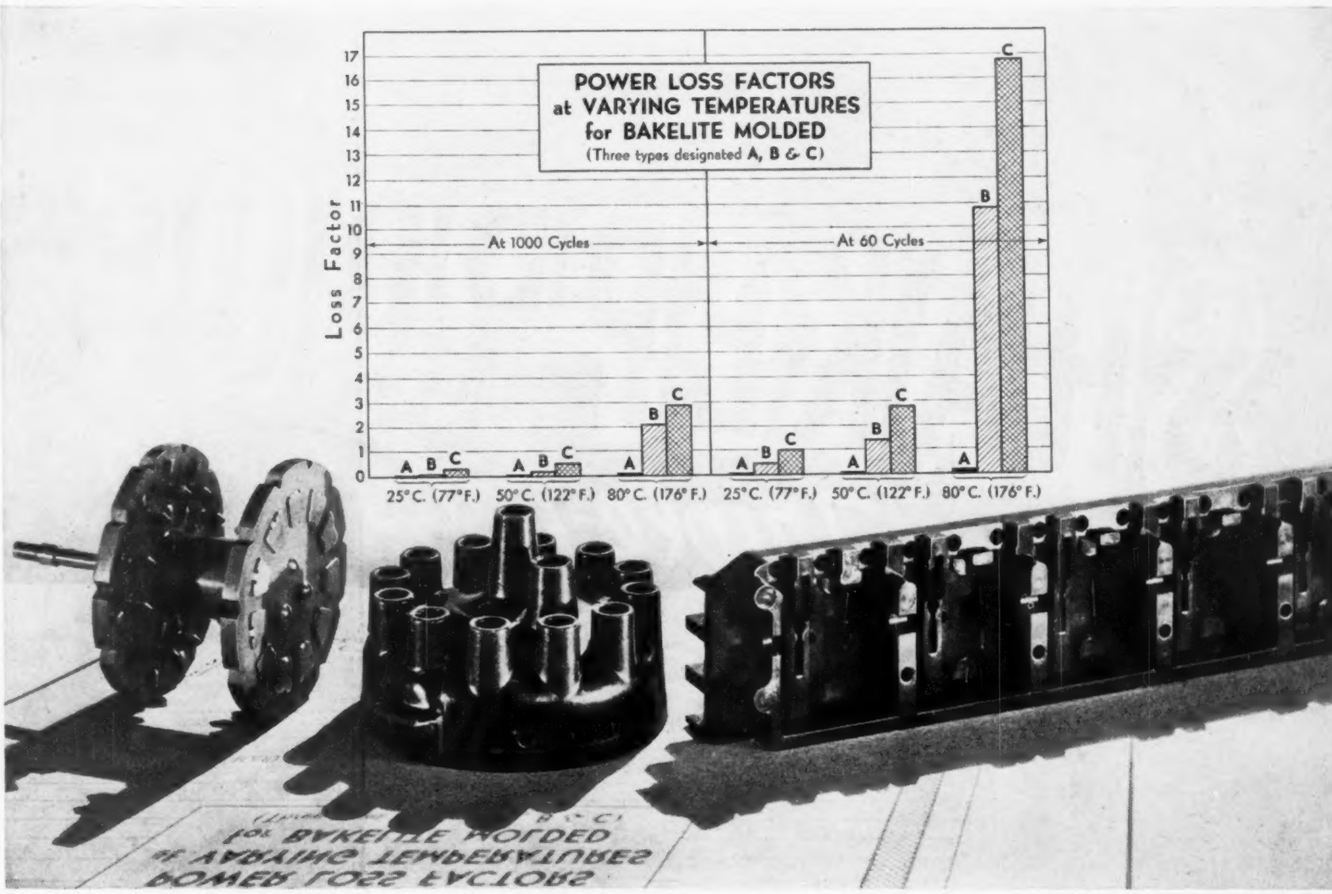
Offices and Agencies in Principal Cities . . . In Canada: ANACONDA AMERICAN BRASS LTD., New Toronto, Ont.

Molded Parts that *Reduce Power Loss*



THE various temperatures at which any electrical device may be called upon to operate—and the variations in electrical frequency, as well—must be carefully considered in selecting dielectrics. Unless power loss of the material remains consistently low throughout the entire range of working temperatures and frequencies, practical efficiency of the device may suffer appreciable losses.

In Bakelite Molded, engineers and designers have available several different dielectrics with differing electrical properties. The diagram, reproduced above, shows a few critical values for the power loss factors of three types of Bakelite Molded. It indicates how well Bakelite Molded meets power loss requirements in nearly any practical range of temperatures and frequencies.

The numerous types of Bakelite Molded now available also provide similar useful variations in other important electrical, mechanical and chemical characteristics. Through proper selection, appropriate combinations may be obtained to meet countless needs of the engineering designer. Our engineers would welcome an opportunity to cooperate with you in determining the type of Bakelite Molded best suited to your needs.

At your request, we will be glad to mail you our illustrated booklet 32M, "Bakelite Molded" containing A. S. T. M. data and other useful information.

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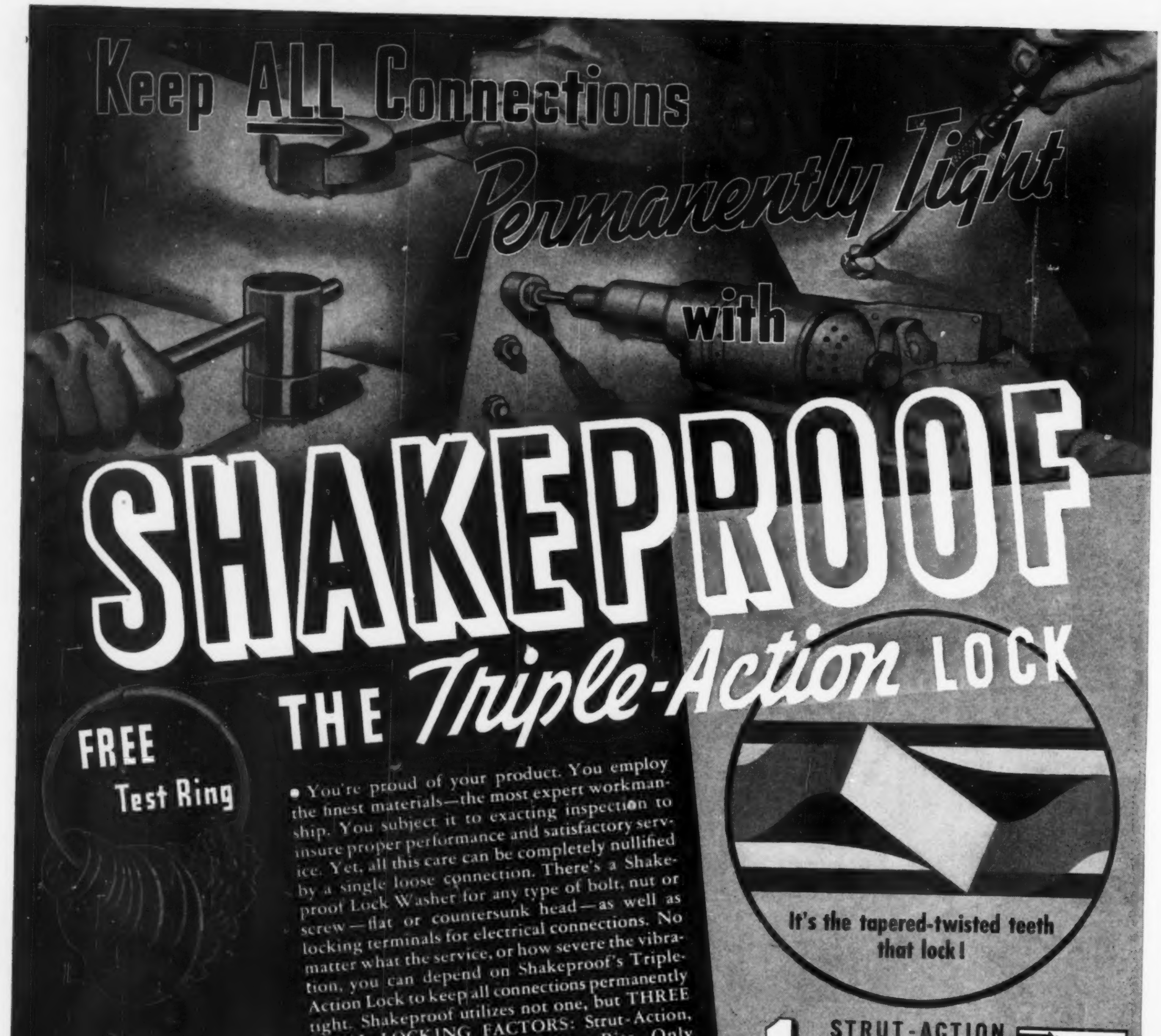
BAKELITE

THE MATERIAL OF A THOUSAND USES


Keep ALL Connections
Permanently Tight
with
SHAKEPROOF
THE Triple-Action LOCK
FREE
Test Ring
• You're proud of your product. You employ the finest materials—the most expert workmanship. You subject it to exacting inspection to insure proper performance and satisfactory service. Yet, all this care can be completely nullified by a single loose connection. There's a Shakeproof Lock Washer for any type of bolt, nut or screw—flat or countersunk head—as well as locking terminals for electrical connections. No matter what the service, or how severe the vibration, you can depend on Shakeproof's Triple-Action Lock to keep all connections permanently tight. Shakeproof utilizes not one, but THREE VITAL LOCKING FACTORS: Strut-Action, Spring-Tension and Initial Line-Bite. Only Shakeproof, with its tapered-twisted teeth, can give you this positive, vibration-defying, triple-action lock.
TEST SHAKEPROOF NOW!
Check our claims for sensational, permanent locking performance by sending for FREE Test Ring. Examine the exclusive tapered-twisted tooth design, and see for yourself why it provides the only Triple-Action Lock! Put Shakeproof Lock Washers to the most searching tests you can devise—and you'll know why they have been adopted by thousands of America's Leading Manufacturers. Write for your free test ring today!
U. S. Patent Nos.
1,862,486—1,909,476—1,909,477
1,419,564—1,782,387—1,604,122
1,963,800
Other Patents—Patents Pending
Foreign Patents.
EXTERNAL TYPE
INTERNAL TYPE
It's the tapered-twisted teeth that lock!
1 STRUT-ACTION
The instant the nut is turned down on a Shakeproof Lock Washer, the tapered-twisted teeth bite into both nut and work surfaces, setting up a sturdy strut-action that provides a powerful leverage against any backward movement of the nut.
2 SPRING-TENSION
When the teeth bite in, a powerful spring-tension is instantly in force. This is produced by the exclusive design of the twisted teeth, which allows the body of the washer to resiliently cooperate in keeping the contact permanently tight.
3 LINE-BITE
The tapered shape of the teeth also assures a substantial line-bite at initial contact. As vibration increases, this bite becomes deeper, making the locking force even greater.
SHAKEPROOF TAPPING SCREWS
with Standard Machine Screw Thread
ACTUALLY CUTS ITS OWN THREAD
WRITE FOR FREE DEMONSTRATION KIT

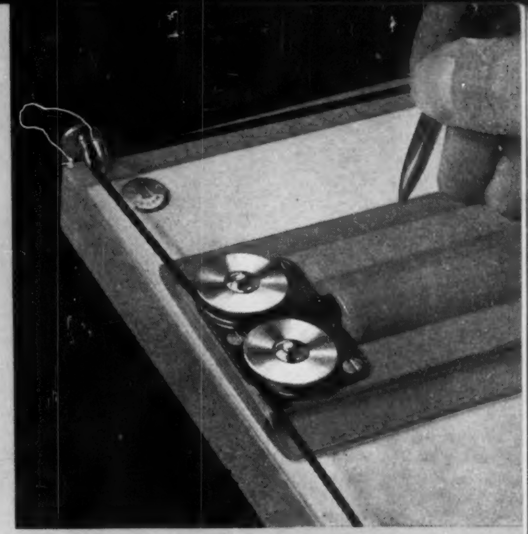
A Spectacular Success

TREMENDOUS DEMAND PROVES INSTANT APPEAL OF THIS PRECISION-BUILT RULING ATTACHMENT

Since its introduction a few weeks ago, the Dietzgen "Premier" Parallel Ruling Attachment has established sales records. Everyone instantly appreciates its outstanding advantages . . . features never obtainable before in *any* parallel ruling attachment. As shown in the photograph below, there are no exposed cords over the work area when you use a Dietzgen "Premier" . . . the cross-over paralleling cords are carried through a reinforcing channel—out of the way. And this reinforced construction means a *flat* straight-edge that *stays* flat on your work. You'll like the many other features of the Dietzgen "Premier," its smoother operation, its bump-proof fastening, its better appearance, etc. Write for illustrated circular or call your Dietzgen representative for a demonstration.

EUGENE DIETZGEN CO.

Chicago • New York • New Orleans • Pittsburgh • San Francisco
Milwaukee • Los Angeles • Philadelphia • Washington



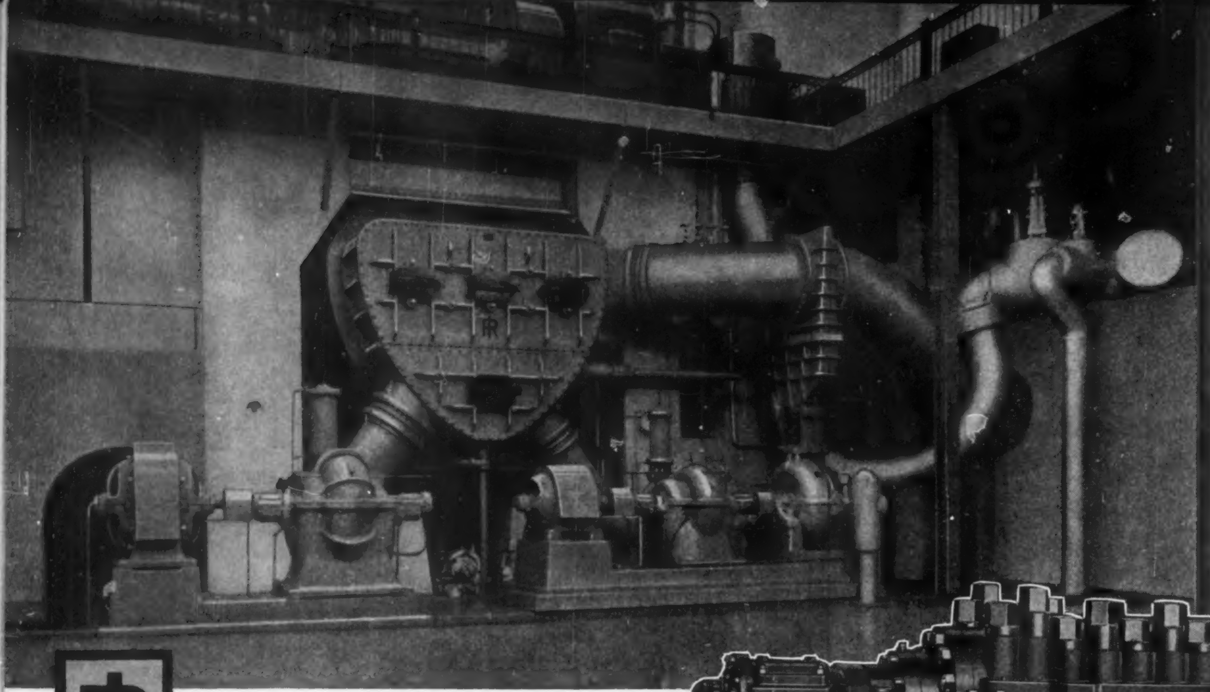
UNRESTRICTED WORKING AREA

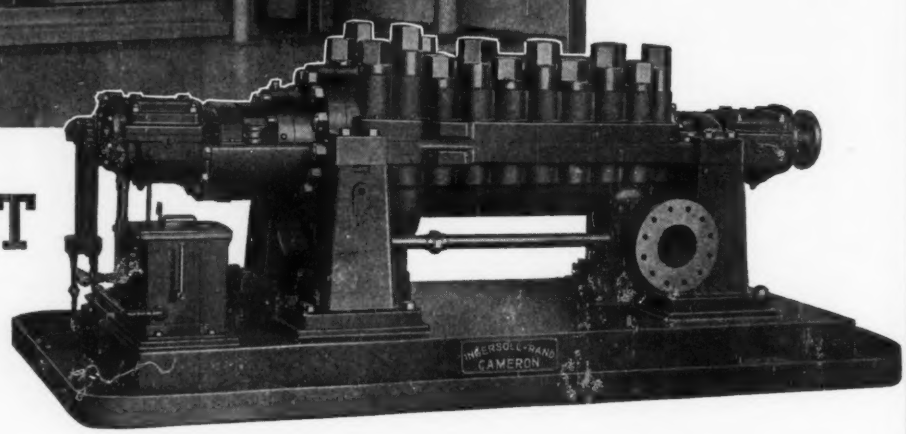
Despite complete elimination of overhanging parts, the Dietzgen "Premier" Parallel Ruling Attachment has no "dead" spots. The entire board from top to bottom and side to side is open working area when you use the Dietzgen "Premier."

The enclosed channel construction not only keeps the cords out of the way, but provides rigid reinforcement for the straight-edge that keeps it flat on your work. You will also be amazed at the comfort and convenience it provides, a straight-edge you can push or pull either way without "thumbing" or smudging your work. Note also that the "Premier" need not extend the full length of your board. May be had in any desired length on special order. Standard lengths are 18 in., 24 in., 30 in., 36 in., 42 in., 48 in., 54 in., 60 in., 72 in., 84 in., 96 in.

DIETZGEN

"PREMIER" PARALLEL RULING ATTACHMENT

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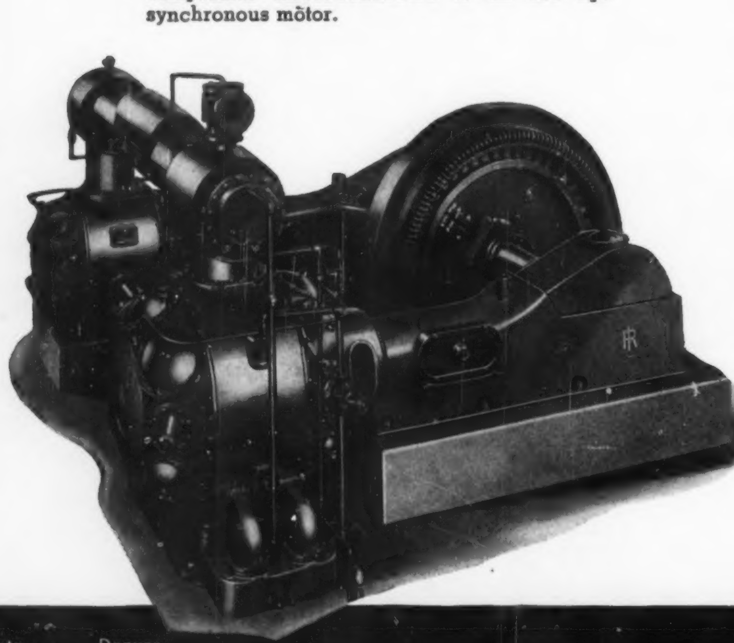
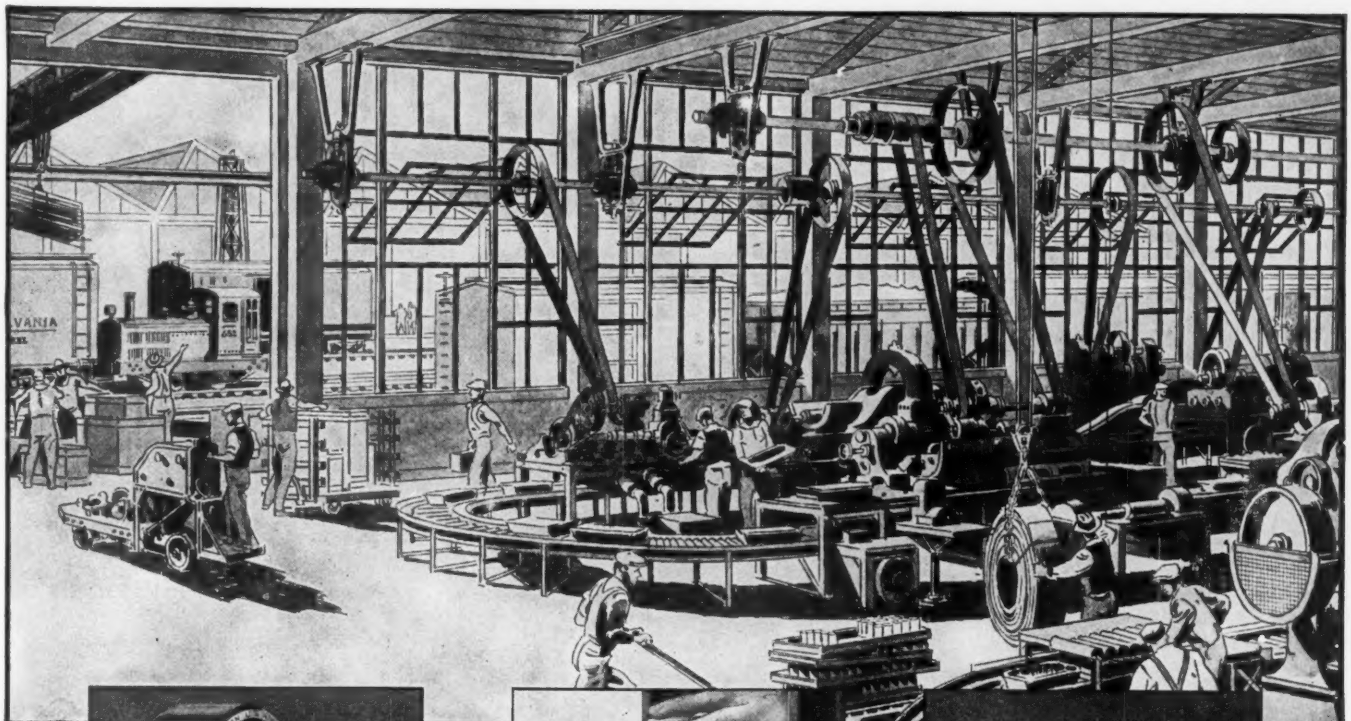
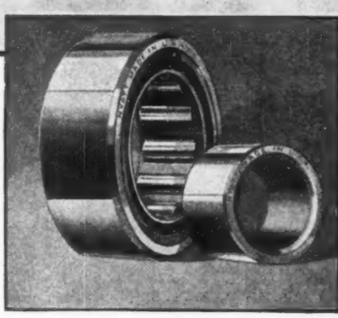
CAMERON

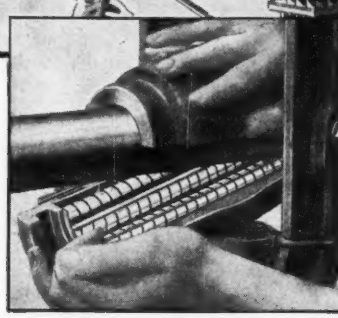


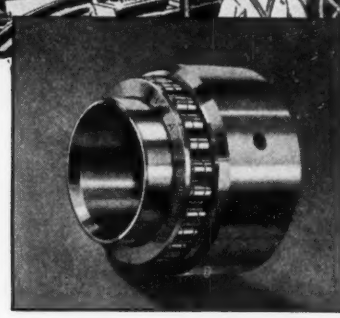
Where Service is *Most* Severe

HYATTS PREDOMINATE









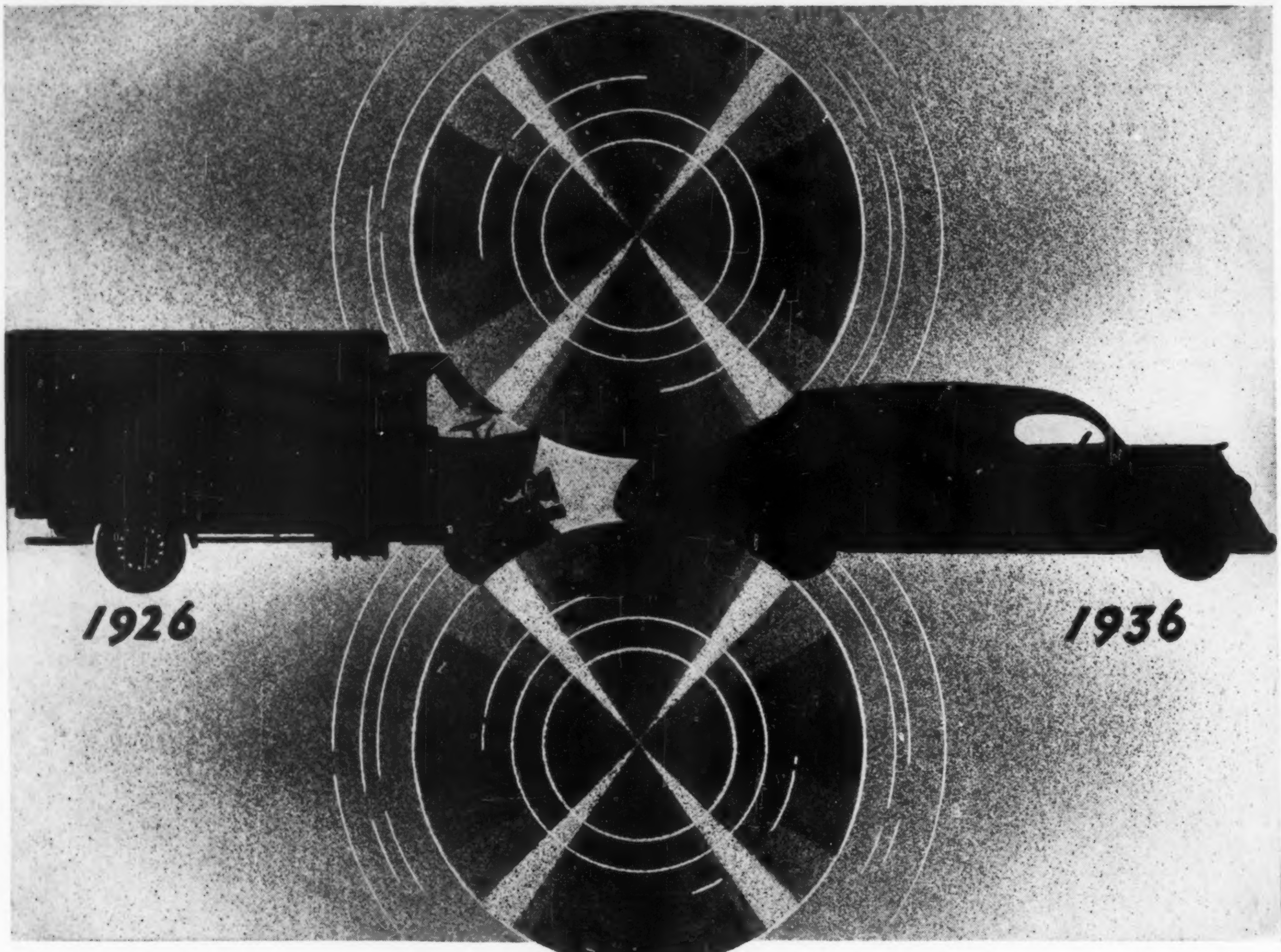
STOPS, starts . . . stresses, strains . . . call for dependable bearings. The millions of hours of carefree machine operation enjoyed every year are largely dependent upon the bearings that carry the load—and a large percentage of these bearings are Hyatt.

In all types of machinery and its complement of motors, line shafting, and material handling equipment, Hyatts serve and save, protect related parts, and take punishment without perceptible wear.

Small wonder, then, that equipment manufacturers continue to use more and more Hyatt Roller Bearings for the better design, better performance, and longer life of their products.

HYATT ROLLER BEARING COMPANY

NEWARK DETROIT CHICAGO PITTSBURGH SAN FRANCISCO



Squeeze the Deadweight

from machinery of every kind

Compare this year's truck with its predecessor of ten years ago. Its weight, price and cost of operation have been radically reduced, with no impairment of safety. In fact it is more dependable, more enduring than ever before. Among the materials that have played an important role in this striking transformation are the Nickel Alloy Steels. Through a partnership with Nickel, the simple steels of yesterday have been rendered tougher and stronger — more highly resistant to shock, stress, fatigue, abrasion and wear. Their greater strength-to-weight ratio offers every manufacturer the opportunity to cut down power consumption and replacement costs. Our experience in the application of Nickel to industrial problems is at your disposal. Send for List "A" of available publications on Nickel and its alloys.

Nickel Alloy Steels

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New Low-Range Direct-Current Arc Welder

A new departure in arc welding, a low-range, direct-current welder, utilizing rectifier bulbs instead of rotating equipment, is being introduced by the General Electric Co., Schenectady, N. Y. The welder, designed to operate on three-phase, 50- or 60-cycle power, 230, 440, or 550 volts, uses four mercury-Tungar bulbs. The new welder has ample capacity for welding all light-gauge car or truck parts in construction and maintenance work. It can be used to fabricate metal roofs and ceilings, steel cabinets, blower and ventilating systems, and steam fittings. Welding operators have found the new welder easy to use—characterizing its arc as "soft." It is lightweight, easily portable, and has a current range of from 25 to 75 amperes, controlled by a nine-point tap switch. The equipment is mounted on hard-rubber casters for easy moving and weighs 140 pounds, net. Overall dimensions are 27 inches by 24 inches by 14 inches.

Beauty in a Bearing

One of the largest spherical roller bearings in the world built by SKF Industries, Inc., Front St. & Erie Ave., Philadelphia, Pa., has the dimensions $46^1/_2''$ outside diameter, $27^1/_2''$ bore and $15^1/_8''$ width. Twenty-three and one-half tons of this one bearing size were purchased by Soviet Russia for their Zaporojstal Steel Works cold mill equipment designed by United Engineering & Foundry Company.

Goetze Gasket Expands

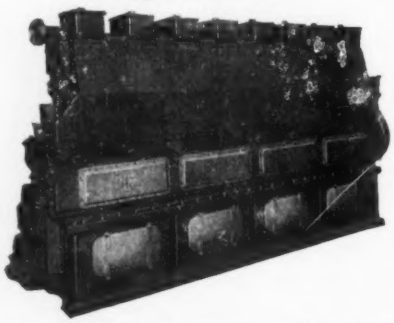
The Goetze Gasket & Packing Co., Inc., 34 Allen Ave., New Brunswick, N. J., has just completed another addition to their plant which was originally located on the present site in 1911. This is the fourth addition which has been necessary since 1928 to keep abreast of a rapidly expanding volume of business.

Former capacity has been practically doubled by this added space and through the installation of new equipment including a number of machines of special design which were developed by their own engineers.

During the past few years considerable effort has been expended in the perfection of new gasket and packing materials to meet the newer conditions. With the increased activity throughout industry improvements in manufacturing processes were also necessary to maintain production schedules.

Among the newer developments are a stuffing box packing of unusually wide adaptability and sheet packing that contains no rubber or other ingredient affected by oil, gasoline or certain chemicals and is suitable for temperatures and pressures greatly exceeding those for which sheet packings have heretofore been recommended.

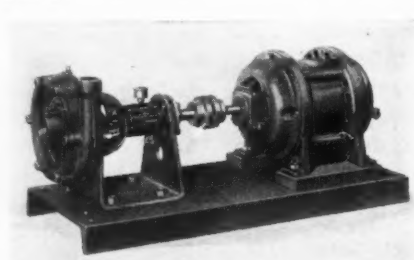
Type S Diesel



Ingersoll-Rand Company, 11 Broadway, New York, N. Y. recently announced its Type S Diesel Engine. This engine is an improved design which is thoroughly modern in all respects. It is of the vertical, four-cycle, single-acting, solid-injection type designed to run at medium speeds and built for heavy-duty, continuous service. The fundamental design is similar to that of the successful Ingersoll-Rand locomotive engine of which there are more than 140 in operation. Some of these have been in service for over 12 years. Type S engines are made with 3, 4, 5, 6 and 8 cylinders for ratings from 150 to 460 horsepower. A new 24 page bulletin describing these engines has just been issued. It may be obtained from any Ingersoll-Rand branch office.

Small Centrifugal Pumps Announced by Worthington

A small, high-quality, low-cost centrifugal pump is announced by Worthington Pump and Machinery Corporation, Harrison, New Jersey.



The utilization of a pressed steel frame combined with quantity production make possible a low cost unit. Simplicity of design results in fewer wearing parts and low maintenance costs. The compactness of the unit makes it easily adaptable to almost any installation within its head capacity range.

The pumps are furnished with direct motor drives or with pulleys for belt drive. The motor sizes range from one-third to three horsepower, delivering from 10 to 130 gallons per minute with heads from 10 to 100 feet.

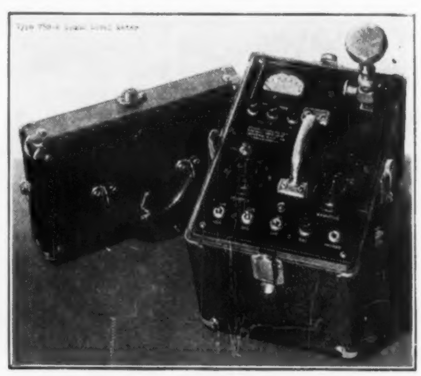
The shaft is supported by two ball bearings enclosed in a dirt proof and moisture proof housing. The suction head is easily removable for inspection of the pump's interior. A choice of standard, all-iron, and all-bronze fittings is offered.

Water supply, circulation, construction work, and pumping on farms are a few of the many uses to which this pump is applicable.

A bulletin showing cross-sectional views and details of construction will be furnished by the manufacturer. Ask for W-310-B5.

Portable Sound Level Meter

The Type 759-A Sound Level Meter recently introduced by General Radio Company, 30 State Street, Cambridge, Mass., has been designed to meet the widest possible range of applications in the general field of sound-level measurement. The performance characteristics are based on the specifications recently adopted by the American Standards Association. The sound intensity range covered by this meter is from 24 to 130 decibels above the standard reference level of 10^{-16} watts per square centimeter at 1000 cycles. The microphone is non-directional and can be used with an extension cord and tripod, if desired.



The calibration is highly stable, and provision is made for recalibration by a simple method. All three frequency-weighting networks accepted by the A.S.A. are included. Power requirements are small, and batteries are self-contained. Mechanically, it is rugged, light in weight, easily portable and attractive in appearance. Provision is made for the use of accessories, such as a vibration pickup. *Dimensions:* $11^1/_2$ x $13^1/_2$ x $9^1/_2$ inches. *Net Weight:* $23^1/_2$ pounds, with batteries. *Price:* Including vacuum tubes and batteries, $195.00.

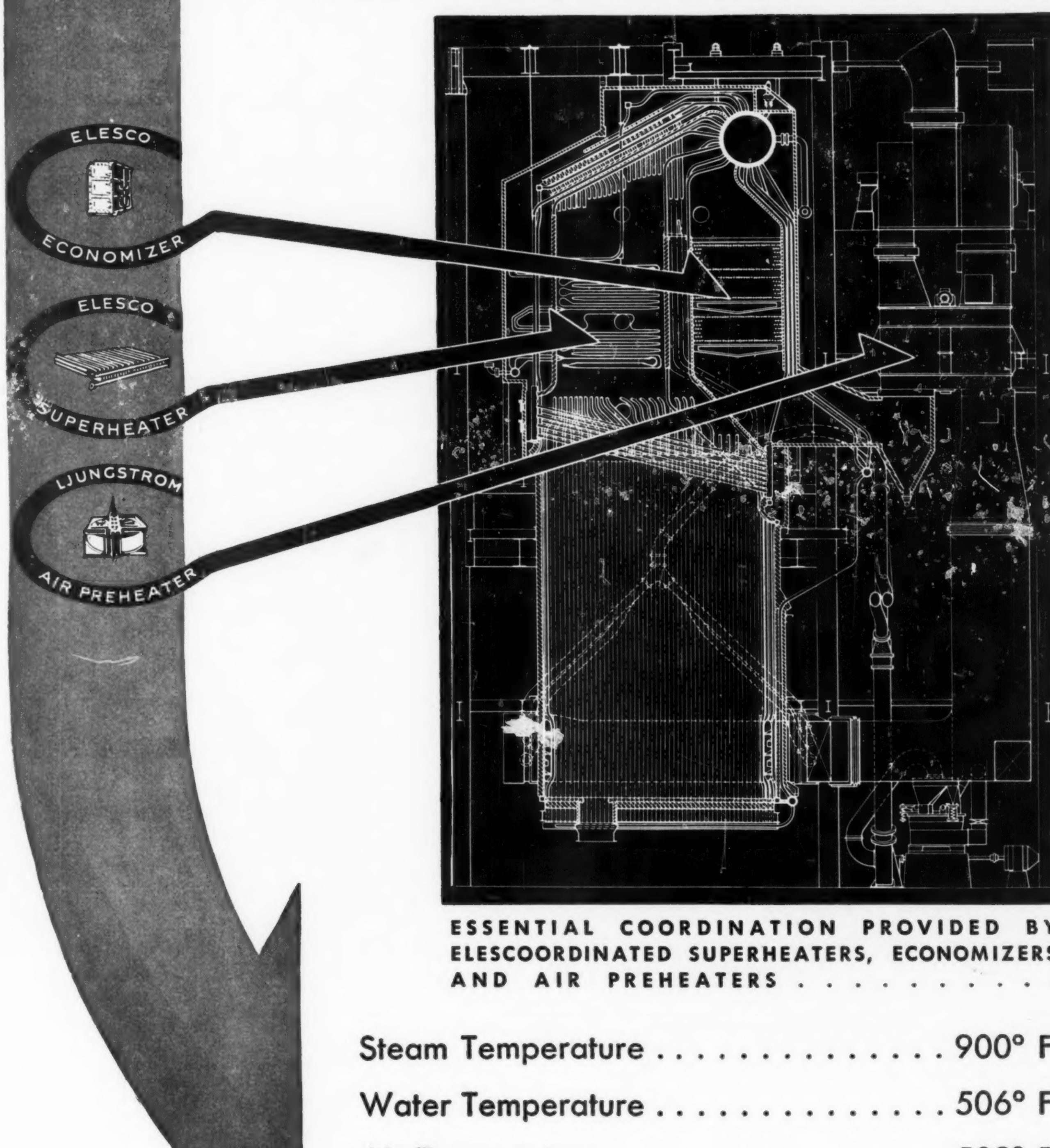
Johns-Manville Industrial Products

The 1936 edition of the Johns-Manville Industrial Products Catalog is now available from Johns-Manville Corporation, 22 East 40th St., New York, N. Y., or through its branch offices. This 60-page book, profusely illustrated, contains a wealth of information and recommendations on high and low temperature insulations for every industrial need, specifications on J-M Bonded Asbestos Builtup Roofs, and J-M Insulated

Continued on Page 24

Expansion . . . . . .

IN THE PLANT OF A LEADING *EASTERN* UTILITY STATION



ESSENTIAL COORDINATION PROVIDED BY ELESCOORDINATED SUPERHEATERS, ECONOMIZERS AND AIR PREHEATERS . . . .

Steam Temperature . . . . 900° F

Water Temperature . . . . 506° F

Air Temperature . . . . 509° F

Capacity per Hour . . . . 500,000 lb.

ELESCO ELESCO SUPERHEATER ELESCO ECONOMIZER LJUNGSTROM AIR PREHEATER ORDINATED

Continued from Page 22

Roofs; detailed information on J-M Corrugated Transite for roofings and sidings: on industrial friction materials; on Transite Conduit, Asbestos Ebony and other J-M electrical materials; on Transite Pressure Pipe for industrial and municipal water lines and on J-M packings.

Among new products described in detail are Transite Korduct, a thin-walled form of asbestos-cement electrical conduit; Rock Cork Pipe Covering, a mineral insulation for low temperature piping, and J-M Ohmstone, a non-impregnated asbestos-cement sheet for switchboard panels that will stand shock and vibration and is immune to carbonization.

The catalog also describes in detail Steeltex Floor Lath and Welded Wire Re-inforcement, and sound control of mechanical equipment.

Bristol Publishes New Set Screws Folder

The Bristol Company, Mill Supply Division, Waterbury, Conn., announces the publication of a new folder, Bulletin No. 833, covering Bristo Screw Products. Prices, sizes, etc., are included for socket set screws, socket head cap screws, stripper bolts, and pipe plugs. Copies will be sent upon request.

New De Laval Bulletin

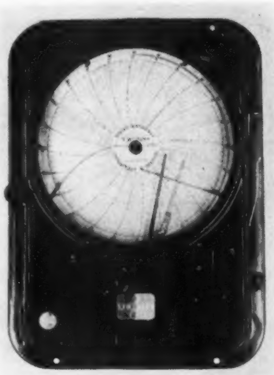
For maximum efficiency, the delivery of a centrifugal pump should be controlled by varying the speed. This is especially true when pumping directly into the distributing piping. The comparative economies of constant speed and variable speed drives for pumps and the several methods of obtaining variable speed are discussed by A. Peterson, Chief Engineer of the Centrifugal Pump Department of the De Laval Steam Turbine Co., Trenton, N. J., in a paper which has been reprinted from the Journal of The American Water Works Association and which will be sent gratis to those interested.

New Bakelite Resin Coatings

The Wipe-On Corporation, 105 Hudson St., New York, N. Y., have brought out a new line of Bakelite Resin products which they call AAA Coatings because of their exceptional resistance to alkali, acids and alcohol. It is reported that these coatings are meeting with great acceptance for maintenance and industrial uses, particularly where the corrosion problem is a factor. They have also helped materially in the wood products industry where moisture resistance has caused such trouble with rotting and warping in southern climates, and in the rayon and dye industries for wood tanks, trays and paddles where rotting and splintering have been problems.

New Low-Range Pressure Recorders and Controllers

The Bristol Company, Waterbury, Conn., announces a new series of low-range recording gauges and controllers, known as the Model D40M series. These instruments are equipped with enclosed bell-type measuring elements and are offered for draft or pressure in minimum ranges of 0 to 0.2 inches of water and maximum ranges of 0 to 2.0 inches of water. Because of the large operating area of the liquid-sealed bell, the measuring element is exceedingly accurate and has the power to respond instantaneously to scarcely perceptible pressure changes.



The control instruments operate on the basic Free Vane principle of pneumatic control which Bristol has used extensively in pressure, vacuum, temperature, humidity, and flow controllers for years. They are equipped with the Ampliset sensitivity adjustment for synchronizing throttling range with process lag. Instruments of this series are compact and self-contained in a 12-inch case. The whole instrument can be easily carried under the arm. Low-Range Model D40M Recorders and Controllers are offered for wall and flush panel mounting. A catalog covering these instruments is available upon request.

Harold Byron Smith Now President of Shakeproof Lock Washer Co.

The board of directors of Shakeproof Lock Washer Company, 2511 North Keeler Ave., Chicago, Ill., on October 27, 1936, elected Harold Byron Smith as President of the Company to succeed his father, the late Harold C. Smith.

The other officers of the Company are now as follows: Frank W. England and Carl G. Olson, Vice-Presidents; Calmer L. Johnson, Secretary and Treasurer; Frank W. England, Assistant Secretary.

Timken Bearings for Aircraft

The Timken Roller Bearing Company, Canton, Ohio, has just published a new section of their Engineering Journal covering the application of tapered roller bearings to landing wheels, tail wheels, swivels and rocker arm assemblies. Complete design data are given, including weights.

Bearing sizes for landing and tail wheels have been standardized by the company in cooperation with the military and naval authorities and the various wheel and tire manufacturers.

This new section is a 16 page $8^1/_2 \times 11''$ unit, punched to fit the standard Timken Engineering Journal. All data presented are coordinated with the ratings which are given in the Journal. Copies of this new Aircraft Section are available on request. The Timken Roller Bearing Company is at all times glad to cooperate with designers and manufacturers in the application and selection of bearings best suited for the duty involved.

The Standards COLUMN

News of Interest to Manufacturers

Circular and Dovetail Forming Tool Blanks

The users of the 20,000 automatic screw machines now in service in the United States will be especially interested in knowing that an American Standard for Circular and Dovetail Forming Took Blanks has just been approved by the American Standards Association. The purpose of this standard is to insure interchangeability as between machines of the different manufacturers and to permit the reduction in the number of blanks now in use.

In order to establish a minimum number of blank sizes, the machines now in use have been classified, for reference purposes, into six different groups of comparable stock capacities. Each group of machines takes a definite size of tool and group numbers have been arbitrarily assigned to identify the size of tool with the machines in which it is to be used.

To facilitate procurement of tool blanks from commercial sources, circular tools have been designated by outside diameter and width of tool blank, and the dovetail tools by group number and width of tool blank.

The organization meeting of the technical committee which formulated this standard was held in New York on March 11, 1931 and in July of the same year a questionnaire covering the design and proportional sizes of circular and dovetail tools was sent to each member of the committee by Chairman W. C. Mueller for comment. In November, 1931 a revised draft was distributed to the committee prior to its second meeting which was held in December, 1931. Subsequently the views of the screw machine builders were obtained and in November, 1932 a further revised draft of the questionnaire was reviewed by the members of the committee and the screw machine builders.

The committee held its third meeting in December, 1932 at which the form and content of the first draft of this proposed American Standard was definitely outlined. Accordingly, in November, 1933 this first draft was completed, duplicated and distributed broadly to manufacturers and users of these blanks for criticism and comment. The response was above the average, replies being received from a majority of those addressed.

Further revised drafts were prepared and studied in September, 1934 and October, 1935, so that, in November, 1935 the technical committee was ready to present its proposal for approval to the Sectional Committee on the Standardization of Small Tools and Machine Tool Elements, C. W. Spicer, chairman. This approval was granted and in May, 1936 the proposed American Standard was submitted to the NMTBA, SAE, and ASME in their capacity as joint sponsors. They in turn transmitted it to the American Standards Association with their complete endorsement in September, 1936.

The technical committee is planning to undertake at a later time the standardization of blanks for hand screw machines as well as holders and straight blade cut-off tools for both hand and automatic screw machines.

For further information—address
The American Society of Mechanical Engineers
29 West 39th St., New York, N. Y.


...and Oil for the MINDS IN YOUR PLANT!
SOCONY-VACUUM Will Help Your Men Better the Work they do for You
YOU WILL FIND that your own men—those who know your problems best — will quickly find use in their daily problems for Socony-Vacuum's friendly cooperation and 70 years of practical experience.
Here, a valuable suggestion; there, a new idea, enable them to work out worth-while efficiencies and economies.
That is why thousands of plants—many in your own locality—will tell you one of the best reasons for doing business with Socony-Vacuum is the kind of help their men get. Try this in your plant and see!
SEE THE FOLLOWING PAGE...

Concerning . . . .
A.S.M.E. ACTIVITIES

Grouping of Divisions

The American Society of Mechanical Engineers has a special contribution that it can make to progress. It is a broad society with members active in technical development in all types of industry. These members are making technical progress in their specific fields which might be exchanged with engineers having some similar problem in other fields.

W. H. Carrier stated some years ago that some of his best achievements were made possible only by following developments in other fields and being on the alert to apply them in his own field of air conditioning.

For some years the Standing Committee on Professional Divisions has stressed the importance of encouraging this inter-exchange of technical information between different types of industries and fields. It has considered that there was a tendency among the professional divisions to get off by themselves and discuss their own specialized problems and in so doing overlook the interconnection between their problems and those in some other field. In an effort to correct this tendency, the Standing Committee started to group divisions under certain departments to facilitate cooperative technical sessions. The departments that have been tentatively formed are:

1. Basic Science
2. Manufacturing Industries
3. Power
4. Management and Administration
5. Transportation.

The first attempt of departmental cooperation was made in the Power field when the following divisions: Steam Power, Fuels, Oil and Gas Power, and Water Power (Hydraulics) were asked to combine in a joint progress report. This year two other cooperative actions were taken. These were the Welding Practice Symposium held in Cleveland, October 22–23, 1936 and the Corrosion Resistant Metals Symposium planned for the 1936 Annual Meeting. These two symposiums were made possible by getting together representatives of the divisions in the manufacturing industries department and formulating a program that fitted their needs. It was from the Textile Division that the first thought came of a symposium on corrosion resistant metals. They were looking at it from their own particular viewpoint, but on further examination it was evident that what was needed was more basic information on corrosion resistant qualities of metals. There are a number of other cooperative activities that have been aided by the stimulation of this Departmental grouping of Divisions. A few of the most active are: Heat Transfer Committee and Drying Committee of the Process Industries Division, and the Aerodynamics Committee of the Aeronautic Division.

The late Dr. Calvin W. Rice stated that the value of the Society to a member was in accordance with his activity in the Society.

A member may profit by the Divisions specialized activites and the new departmental cooperative activity in accordance with his willingness to contribute and exchange his experiences in discussions and papers.

The Standing Committee on Professional Divisions and the program committees of Divisions always welcome suggestions from members as to papers and topics for discussion at future meetings. Programs for meetings are started six to eight months ahead of a meeting and papers should be in the hands of society program committees at least three months in advance of the meeting.

For further information—address

The American Society of Mechanical Engineers
29 W. 39th St., New York, N. Y.

Calendar of
MEETINGS and EXPOSITIONS

DECEMBER

1-4 **American Society of Mechanical Engineers,** 57th Annual Meeting, Engineering Societies Building, New York, N. Y.

There will be many special events this year, among them being: Paper on Steamotive, a self-contained power unit. Will it displace the Diesel? . . . Corrosion Resisting Metal Symposium containing papers by leading experts . . . Westinghouse Anniversary Celebration . . . Over 25 technical sessions, social events, lectures and plant trips.

1-5 **Twelfth National Exposition of Power and Mechanical Engineering,** Grand Central Palace, New York, N. Y.

2-4 **American Society of Refrigerating Engineers,** 32nd Annual Meeting, New York, N. Y.

14-19 **Society of Naval Architects & Marine Engineers,** International Meeting, Waldorf Hotel, New York City.

28-Jan. 2 **American Association for the Advancement of Science,** Atlantic City, N. J.

JANUARY

1-2 **American Association for the Advancement of Science,** Atlantic City, N. J.

11-15 **Society of Automotive Engineers,** Annual Meeting, Detroit, Michigan.

20-22 **American Society of Civil Engineers,** Annual Meeting, New York, N. Y.

25-27 **American Society of Heating and Ventilating Engineers,** 43rd Annual Meeting, Hotel Statler, St. Louis, Mo.

25-29 **American Institute of Electrical Engineers,** Winter Convention, New York, N. Y.

27-29 **Institute of Aeronautical Science,** Annual Meeting, New York, N. Y.

FEBRUARY

Wk. of 15th **American Institute of Mining and Metallurgical Engineers,** Annual Meeting, New York, N. Y.

25 **Association of Iron and Steel Engineers,** Youngstown, Ohio.

A.S.M.E. GUIDE

NATIONAL POWER SHOW

Twelfth National Exposition of Power and Mechanical Engineering

Grand Central Palace, New York, N. Y. November 30th to December 5th, 1936

THE "A.S.M.E. Guide" to the National Power Show is again presented by MECHANICAL ENGINEERING and contains a "List of Exhibitors" which appears on pages 35 and 37 and which has been submitted to the Management of the Exposition for final checking. Its accuracy in detail is not guaranteed because of inevitable changes between the date of going to press and the opening of the Show. In this list the numbers of booths occupied are given and by referring to the floor-space diagrams shown on page 39, a user of the Guide at the Show can readily locate any booth in which he is interested. A.S.M.E. members are especially invited to visit the A.S.M.E. Booth (No. 80) on the main floor near the front entrance, where full information regarding A.S.M.E. activities and publications will be available.

Three entire floors of the Grand Central Palace will be devoted to exhibits of equipment and products which have been designed to meet current needs. Machinery will be in operation. All the effective principles of modern display will be utilized to show products so that they may be easily inspected and so that attention will be drawn to their new and important features. Competent men from exhibitors' technical staffs will answer visitors' questions, demonstrate products, and explain how principles may be applied to the specific problems which confront the inquirer. The comprehensive presentation, including the latest output of competitive manufacturers, will provide visiting executives and engineers with a sound basis for their comparison of relative advantages.

The Exposition this year is expected to be more comprehensive than in the past. The improvement in business will be one influence, and the great interest which manufacturers have developed in their products through research developing new products and improvements on standard products will make the Exposition very interesting. Classifications of equipment on display will include: fuels, combustion equipment; refractories, steam generating equipment; steam distribution equipment; piping and fittings; prime movers, pumps and hydraulic equipment; electric generators and motors; electrical transmission, distribution, control; power transmission; control apparatus and precision instruments; power-driven machinery; tools and machine tools; material handling equipment; heating, ventilating, refrigeration, air conditioning; lubricants; operation and maintenance materials.

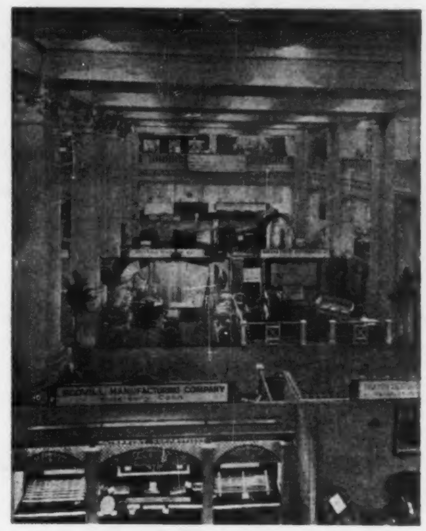
There will be large and heavy equipment from equipment used in the generation of power, its distribution and utilization through mechanical equipment for handling materials, tools and various other mechanical devices. There will be the usual large grouping of refractories, stokers, burners and fuel burning equipment of various types, boilers and power generating equipment, engines, pumps and steam equipment, piping, valves, fittings, showing all the recent developments in these lines, and supplies used co-incidental thereto, instruments of precision for control and measurement of volume, speed, rate of flow, pressure, time and other numerous factors which must be known in industrial operations. There will be the whole range of material supplies, lubricants, packing, belting and other incidental products, tools and machine tools, etc.

In the field of piping, valves, and fittings, a variety of interesting products will be displayed. There will be high speed ringplate valves for ammonia, air and gas compressors, also float valves for level control of liquid ammonia. A compressor valve machined from solid alloy steel forgings will be featured. New to many engineers will be the ringplate valves designed for pressures up to 4,000 pounds, made from stainless steel and oil-hardened.

Exhibits of fans, blowers and unit heaters will include fans which emphasize extremely quiet operation, attractive appearance, and air movement comparable with that produced by airplane propellers.

Transmission equipment will be shown by a number of manufacturers. There will be a display of the latest developments in the use of ball, roller, and thrust bearings; also ball and roller-bearing-equipped pillow blocks. Power transmission equipment will include silent and roller chain drives, herringbone, worm, and motorized helical gear reducers; also variable speed transmission and roller flexible couplings. Related equipment will include an improved all-steel coupling designed to absorb shock loads and to compensate for parallel and angular misalignment. Special belt drives will be demonstrated for power transmission over the complete range—from fractional to a thousand horsepower. For oily jobs there will be oil-proof belts.

Of interest to many fields, including the fabricators of synthetic plastics will be an exhibit of seamless flexible metal hose and fittings. In the same field, self-flaring cop-



per tube fittings will be featured with the claim that they eliminate the use of flaring tools.

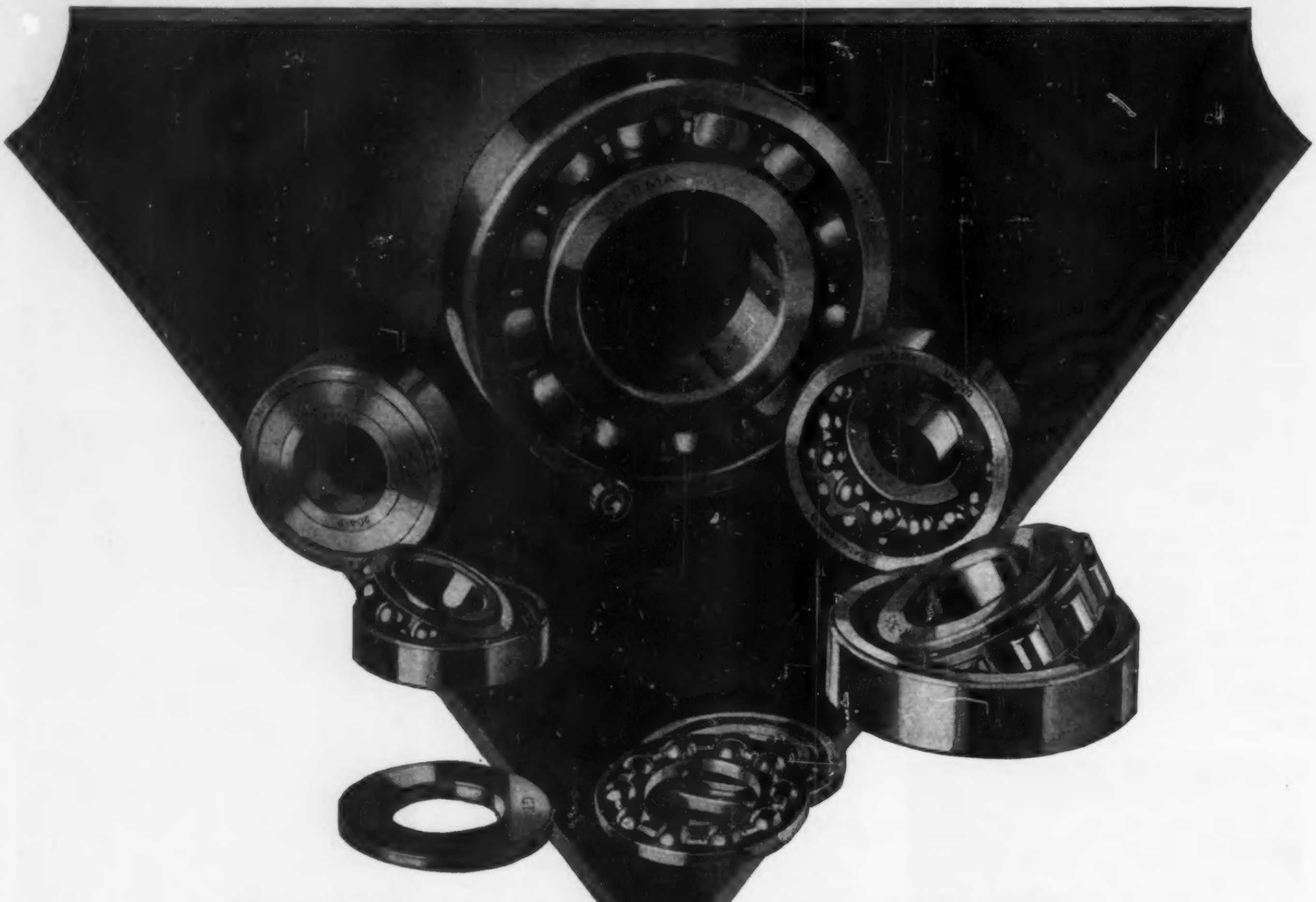
Machine tool exhibits will include high speed and heavy duty metal sawing machines, some with hydraulically operated bar feed. Sawing equipment will include metal cutting band saws and a new double rotary saw designed for high production. There will be a demonstration of the cutting of various materials by means of abrasive saws.

Exposition week is the heyday of some industries' purchasing departments and other industries' sales departments. It offers both departments the opportunity to cut down on expenses and loss of time, which, were there no exposition, would be expended in extra travelling—in one case, to various manufacturers; in the other, to consumers scattered all over the world. To the Eleventh Exposition visitors came from 1036 cities and towns in 41 states of the United States, 55 cities in 26 foreign countries, 5 cities and towns in United States Foreign Possessions.

As in previous years, the National Power Show is being held during the same week as the A.S.M.E. Annual Meeting; and a special invitation is extended to all A.S.M.E. members to attend. Tickets of admission can be had without charge at Society Headquarters; and an A.S.M.E. emblem seldom fails to secure for its wearer even more than the usual degree of courteous attention accorded to visitors at booths. In many cases the managers of the booths are A.S.M.E. members themselves; and are glad, accordingly, to welcome a visitor with whom they have a common interest.

See Pages 35 and 37 for List of Exhibitors

See Page 39 for Floor Diagrams



PRECISION BEARINGS

in 108 distinct series

To the machinery world, NORMA-HOFFMANN offers the most complete and comprehensive line of anti-friction bearings in America—108 distinct series—a PRECISION Bearing for every load, speed and duty.

Many of these have been pioneered, or specially developed, by NORMA-HOFFMANN engineers to meet specific requirements as revealed by advancing methods in machine design, manufacture and operation.

In times past, engineers often had to adapt their designs to the comparatively few standard bearing types then available. Today—with the wide range of types and sizes afforded by the standard NORMA-HOFFMANN PRECISION line, such compromise is seldom necessary.

In the 108 PRECISION Series are included: ball, roller, needle and thrust bearings; open, closed, and angular contact bearings; radial and self-aligning types; single and double row types; felt-protected, shielded, snap ring and self-sealed types. The size range is from ⅛- to 21-inch bore, embracing both metric and inch sizes. PRECISION Ball and Roller Bearing Pillow Blocks are also available in an extensive range of sizes.

Write for the Catalog. Let our engineers work with yours.

"NORMA-HOFFMANN"

PRECISION BEARINGS

BALL. ROLLER AND THRUST

NORMA-HOFFMANN BEARINGS CORPN., STAMFORD, CONN. U.S.A.

LIST of EXHIBITORS

Twelfth National Exposition of Power and Mechanical Engineering

Main Floor: Booths 1 to 95 Second Floor: Booths 200 to 348 Third Floor: Booths 401 to 629 *See Floor Diagrams on Page 39*

(Corrected to November 18th, 1936, from list supplied by International Exposition Co.)

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Abrams, Morris (Inc.)	483, 484
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Allis-Chalmers Mfg. Co.	3
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Reeves Pulley Co.	34, 35
Reliance Gauge Column Co.	90

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Firms Listed in Bold Face are Advertisers in this Section


THE GENUINE
Squires
STEAM TRAP
A simple, sturdy trap for high or low pressure steam—can be used on steam, air or gasoline—and is easily accessible.
It is adaptable to a wide range of application—high pressure power plants, marine service, low pressure heating systems, blast service, laundry machinery steam separators, rubber vulcanizers, dry kilns and any place that requires a dependable trap.
Quick Acting Water Sealed
If interested in better Trap Service at low cost, Reducing Valves that will reduce pressure up to 500 lbs. to ounces without the aid of secondary valves, Pump Governors for all service, or Boiler Feed Water Controllers—write for literature H-1—visit Booth No. 252 at the Power Show.
Squires
The C. E. Squires Company
EAST 40th STREET AND KELLEY AVENUE
CLEVELAND, OHIO

LIST of EXHIBITORS

Twelfth National Exposition of Power and Mechanical Engineering

Main Floor: Booths 1 to 95 Second Floor: Booths 200 to 348 Third Floor: Booths 401 to 629 ***See Floor Diagrams on page 39***

(Corrected to November 18th, 1936, from list supplied by International Exposition Co.)

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Power Session

Domestic Oil Burners, by A. H. Senner

Steamotive—A Complete Generating Unit, Its Development and Test, by E. G. Bailey, A. R. S. Smith, and P. S. Dickey

Undercooling in Steam Nozzles, by J. T. Retaliata

Tests of a Large Surface Condenser at Widely Varying Temperatures, Velocities of Inlet Water and Loads, by G. H. Van Hengel

Physical Property Uniformity in Valve-Body Steel Castings, by A. E. White, C. L. Clark and S. Crocker

Unique Design Features and Operating Experiences at the Port Washington Power Plant, by F. L. Dornbrook

Heat Transfer

Problems in the Collection and Evaluation of Data for Design of Steam-Generating Units, by B. J. Cross

The Thermal Conductivity of Liquids, by J. F. Downie Smith

Temperature and Combustion Rates in Fuel Beds, by M. A. Mayers (to be presented by title)

Discussion of Heat-Transfer Activities

Cinder Catchers

Fuels Panel Discussion

Discussers: W. G. Christy, H. F. Johnstone, C. W. Hedberg, Ollison Craig, H. F. Hagen, L. C. Thiton, Jr., Paul Thompson, J. J. Grob, H. P. Hardie, C. S. Messler, M. D. Engle, J. H. Leitch, H. B. Reynolds, Stanley Brown

Oil and Gas Power

Supercharging of Internal-Combustion Engines with Blowers Driven by Exhaust-Gas Turbines, by A. Buchy, Wintethur, Switzerland

Diesel-Engine Operating, Maintenance, and Outage Data, by Lee Schneitter

Discussion of Oil-Engine Cost-Data Report

Power and Applied Mechanics

Superposed Turbine-Regulation Problems, by A. F. Schwendner and A. A. Luoma

Turbine Supervisory Instruments and Records, by J. L. Roberts and C. D. Greentree

Supervising Instruments for 165,000-Kw Turbine at Richmond Station, H. Steen-Johnsen

Boiler Feedwater

Discussion of Boiler-Feedwater Problems to include Progress Report on Embrittlement and Dissolved Oxygen Determination

Reactions of Sodium Sulphite under Boiler Operating Conditions, by Prof. F. G. Straub

Turbine History

The Steam Turbine in the United States

I—Development by the Westinghouse Machine Company, by E. E. Keller and F. Hodgkinson

II—Early Development by the Allis-Chalmers Manufacturing Co., by A. G. Christie

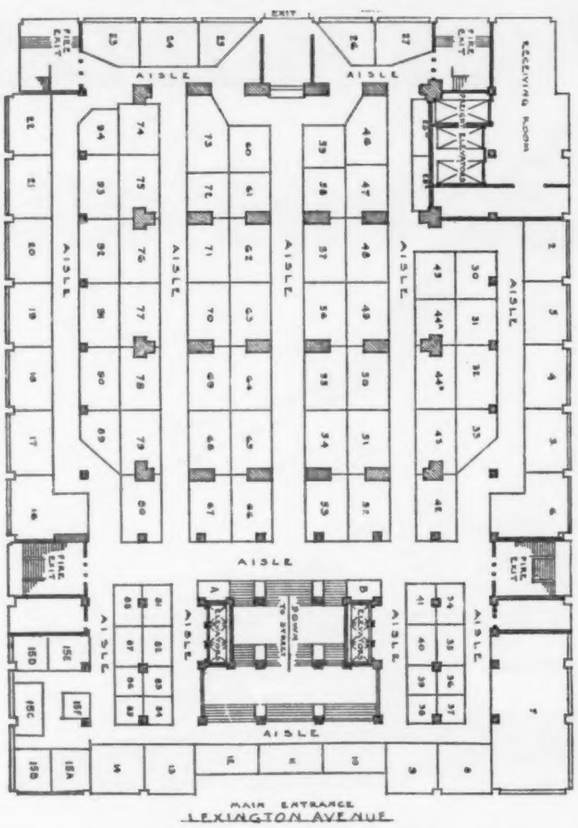
III—A Brief History of Steam-Turbine Development by the General Electric Co., by E. L. Robinson

FLOOR DIAGRAMS

Twelfth National Exposition of Power and Mechanical Engineering

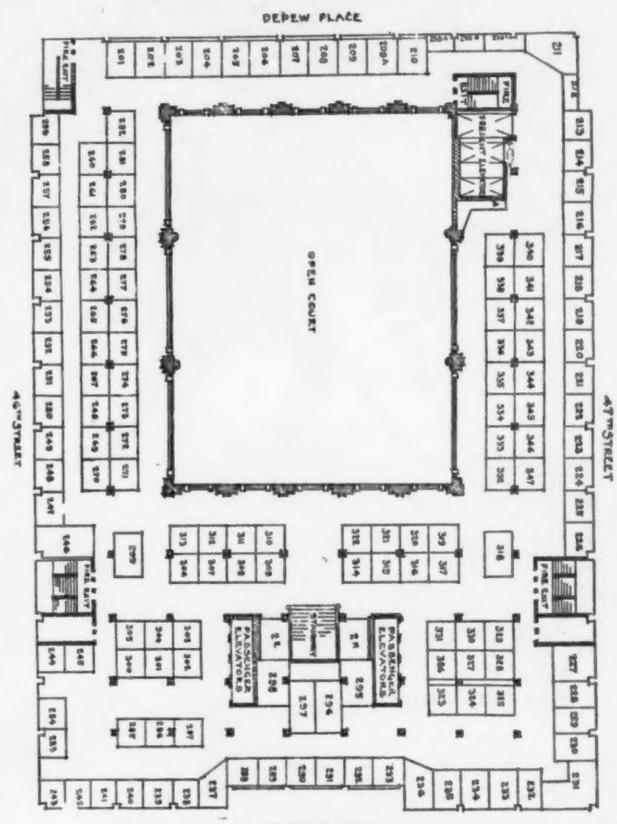
November 30th to December 5th, 1936 **Grand Central Palace, New York, N. Y.**

FIRST FLOOR



BOOTHS NOS. 1-95

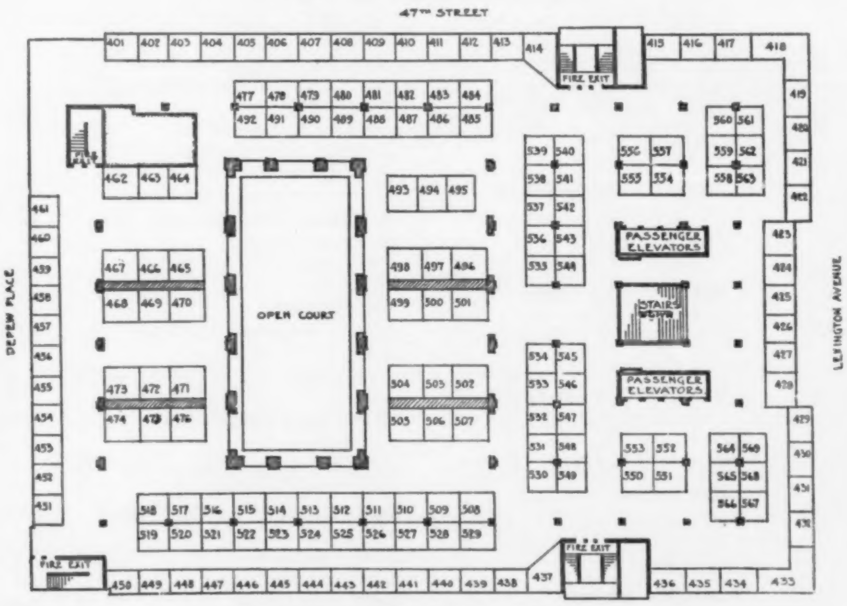
SECOND FLOOR



BOOTHS NOS. 200-348

THIRD FLOOR

See page 33 for Story of the Show



See pages 35 and 37 for List of Exhibitors

BOOTHS NOS. 401-629

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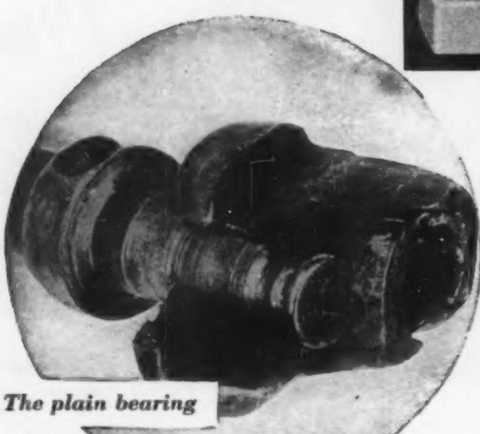

• *The plain bearing*

and what it may do.

WASTED POWER...power lost in the form of friction... *must* be paid for. It's the product of plain bearings which *wear the shaft, accumulate dirt owing to the spread of oil, and require constant lubrication and attention.*

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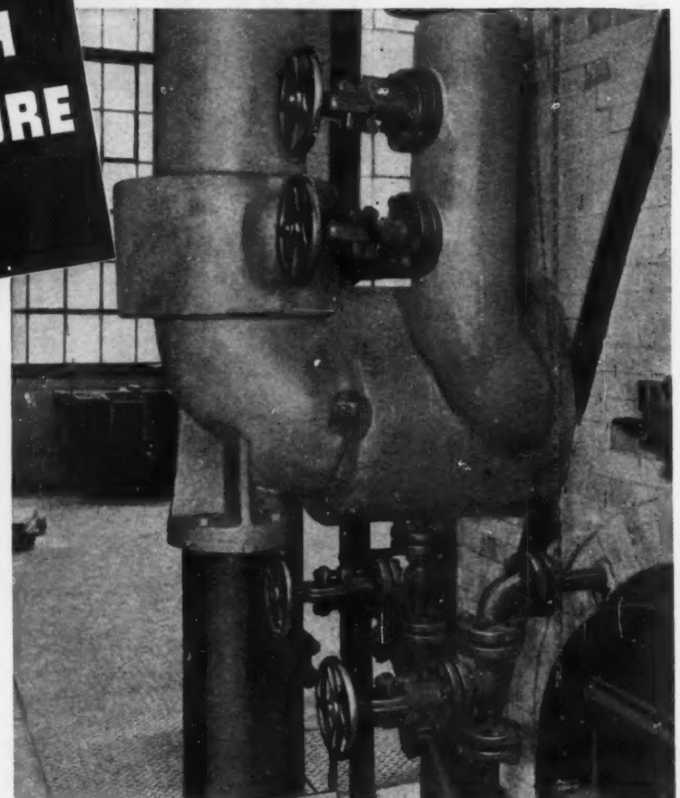
SKF INDUSTRIES, INC., Front St. & Erie Ave. Philadelphia, Pa.

3701

SKF PILLOW BLOCKS

Triplex Steel
BOLT-STUDS FOR HIGH PRESSURE-TEMPERATURE CONDITIONS

For dimensions, list prices, thread and nut data on Crane Triplex Steel Bolt-Studs see page 355, new Crane No. 52 Catalog. Complete technical data on Crane bolting is given on pages 724 and 725, including tables showing the relation between torque and bolt stress.



● The use of higher and higher steam pressures and temperatures demands much of bolt-stud metals. Crane Co.'s metallurgical department anticipated the requirements of higher pressures and temperatures and produced the metals to cope with them. Continuous research has provided the right materials for each successive boost in pressures.

Crane Triplex Steel Bolt-Studs of chrome-nickel steel, for instance, have ample reserve strength to meet the most severe temperature-pressure combinations now in use. Should still further increases be made in pressures and temperatures, Crane Co. is ready to meet the conditions.

The Crane line of valves, fittings and fabricated piping is complete. A branch or distributor is nearby, ready to serve you.

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WHERE service conditions are most severe—where loads are heaviest—where impact, momentary overloads, and vibration are a problem—there NORMA-HOFFMANN PRECISION ROLLER BEARINGS demonstrate their extraordinary ability to absorb punishment.

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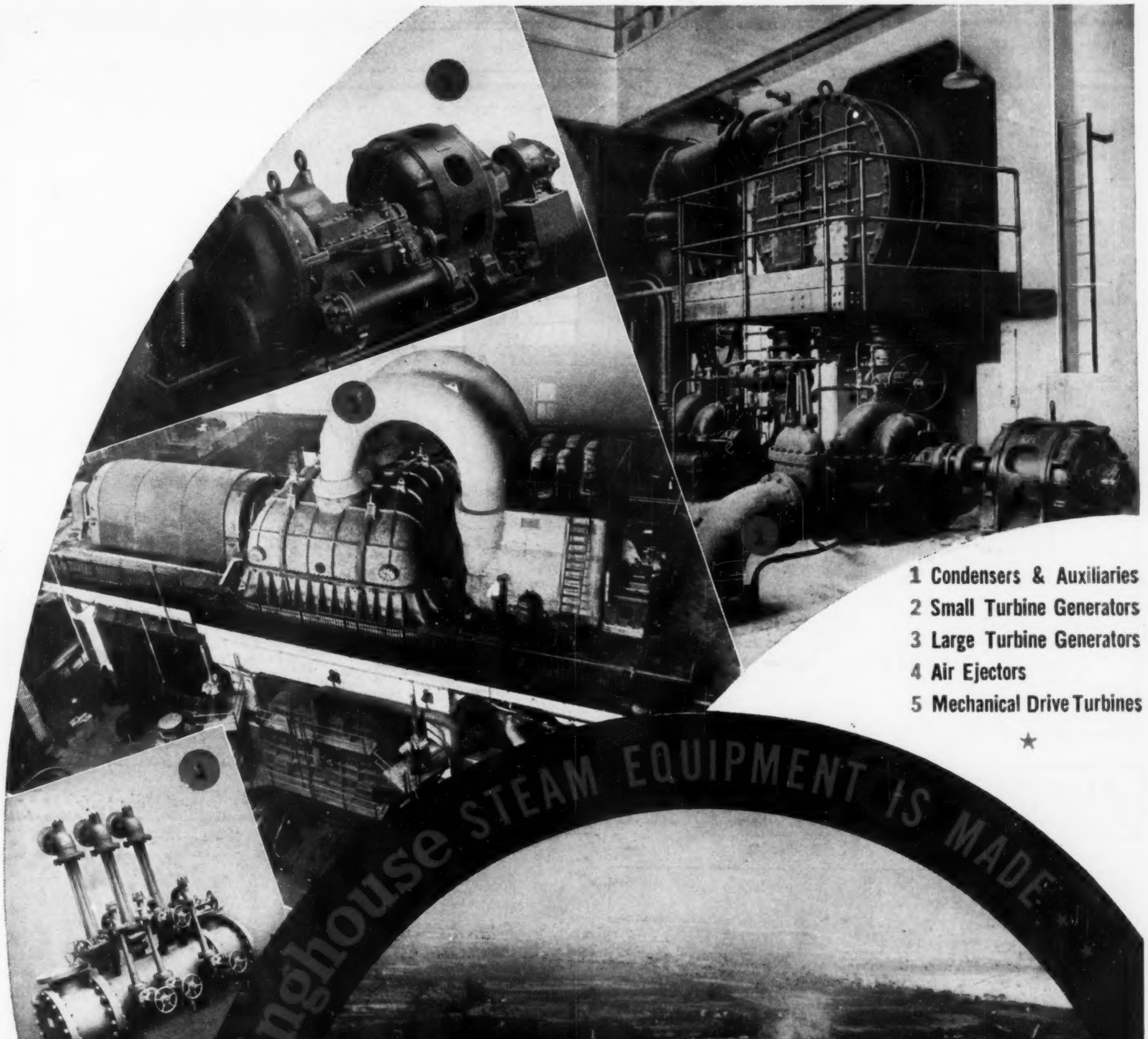
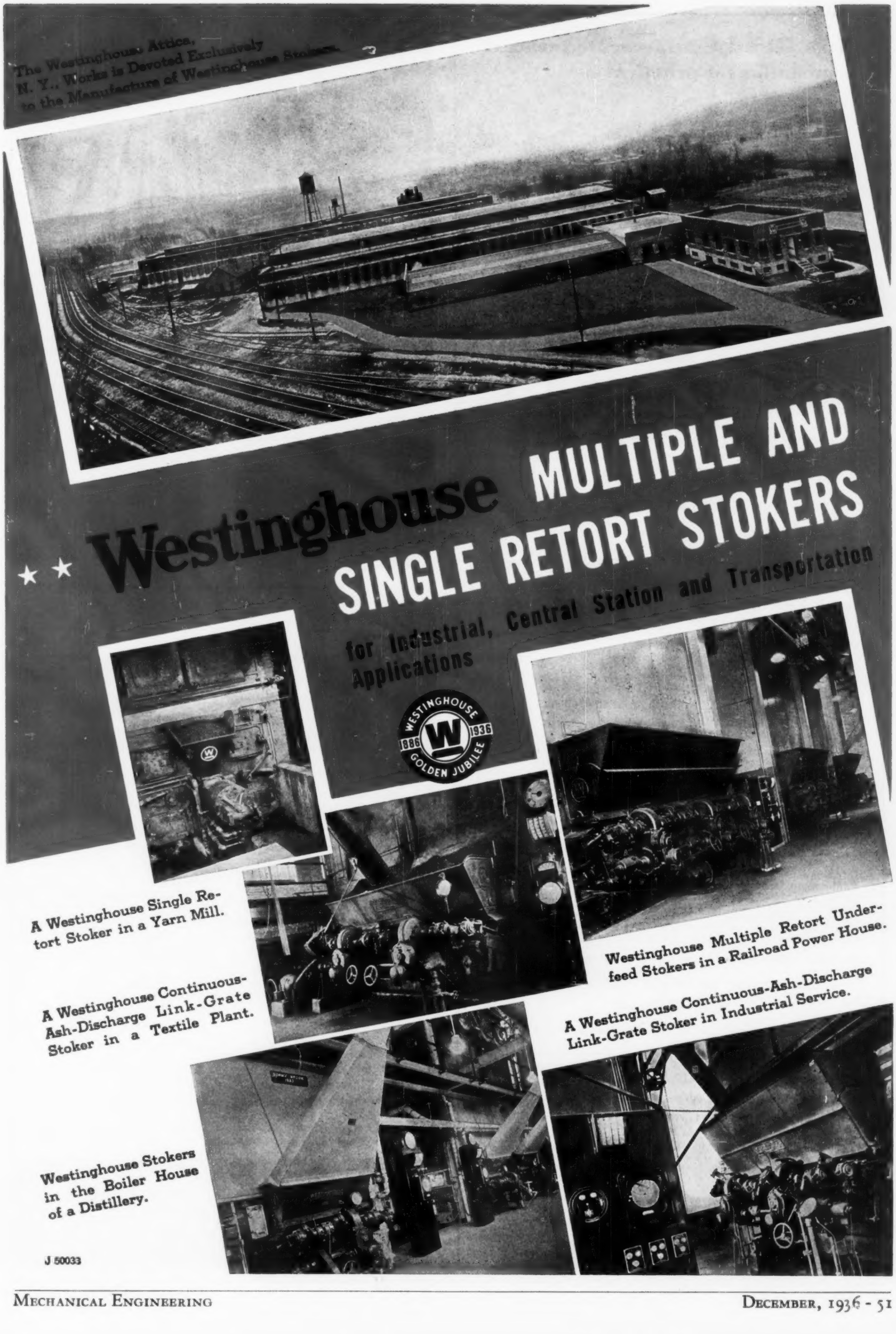
PRECISION BALL, ROLLER and THRUST BEARINGS

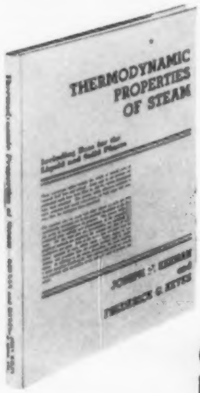
NORMA-HOFFMANN BEARINGS CORPN., STAMFORD, CONN. U.S.A.


1 Condensers & Auxiliaries
2 Small Turbine Generators
3 Large Turbine Generators
4 Air Ejectors
5 Mechanical Drive Turbines
WHERE Westinghouse STEAM EQUIPMENT IS MADE
WESTINGHOUSE 1886 W 1936 GOLDEN JUBILEE
SOUTH PHILADELPHIA WORKS, PHILADELPHIA, PA.
Westinghouse Electric & Manufacturing Company
J 50034



The Westinghouse Attica, N. Y., Works is Devoted Exclusively to the Manufacture of Westinghouse Stokers.
Westinghouse MULTIPLE AND SINGLE RETORT STOKERS
for Industrial, Central Station and Transportation Applications
WESTINGHOUSE 1886 W 1936 GOLDEN JUBILEE
A Westinghouse Single Retort Stoker in a Yarn Mill.
Westinghouse Multiple Retort Underfeed Stokers in a Railroad Power House.
A Westinghouse Continuous-Ash-Discharge Link-Grate Stoker in a Textile Plant.
A Westinghouse Continuous-Ash-Discharge Link-Grate Stoker in Industrial Service.
Westinghouse Stokers in the Boiler House of a Distillery.
J 50033

Now Ready—An accurate, inclusive compilation for practical use



See this book ON APPROVAL

$2.75

KEENAN-KEYES'

STEAM TABLES

By Joseph H. Keenan, *Associate Prof. of Mechanical Engineering* and Frederick G. Keyes, *Prof. of Physicochemical Research, Director of the Research Laboratory in Physical Chemistry, Chairman of the Department of Chemistry*

Both at Massachusetts Institute of Technology

These convenient tables include the results of several years of research both here and abroad. Large gaps in the previous experimental work have been filled in, and the regions investigated have been extended. The present tables therefore constitute a more complete and useful compilation, in both range and accuracy, than has heretofore been assembled.

Valuable Features

1. For the first time a table is presented which extends continuously from vapor to liquid states above the critical point.
2. An enlarged Mollier chart of steam properties is included.
3. The book contains an international table whose values are within tolerances set by the Third International Steam Tables Conference.
4. It includes auxiliary data, such as tables showing viscosities, heat conductivities, properties of ice and compressed liquid water, and extensive conversion tables, together with special charts of isentropic coefficients, heat capacities, and temperature entropy properties.
5. Its tables include the greatest range of pressures (0 to 5500 or 6000 lb./sq.in.) and of temperatures (—40 to 1600°F) ever covered in steam tables.

The Contents

Introduction
Bibliography
Symbols Used in Tables
Saturation: Temperatures
Saturation: Pressures
Superheated Vapor
Compressed Liquid
Saturation: Solid-Vapor
Viscosity
Heat Conductivity
Conversion Factors
Thermometer Calibration Formulas
Logarithms to the Base 10
Logarithms to the Base *e*

Thermodynamic Properties of STEAM

Including data for the liquid and solid phases

FREE EXAMINATION OFFER

John Wiley & Sons, Inc., 440 Fourth Avenue, New York, N. Y.

Gentlemen: Kindly send on ten days' approval Keenan and Keyes' "Thermodynamic Properties of Steam." If satisfied, I agree to remit $2.75; otherwise the book will be returned to you postpaid.

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Employed by...

ME 12-36

DESIGN—Engineered by experienced men, with many years of training in meeting the problems of GEAR manufacturing.

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PLANT—Manufactured in a most completely equipped and versatile GEAR producing plant.

TYPE OF GEAR—We make all types of gears—and have had almost 50 years' experience in GEAR cutting and generating.

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RESULT—Smooth meshing gears—yet very powerful—minimizing your production problem.

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1120 W. MONROE STREET • CHICAGO, ILLINOIS
ESTABLISHED 1888

Do YOU know the Answers?

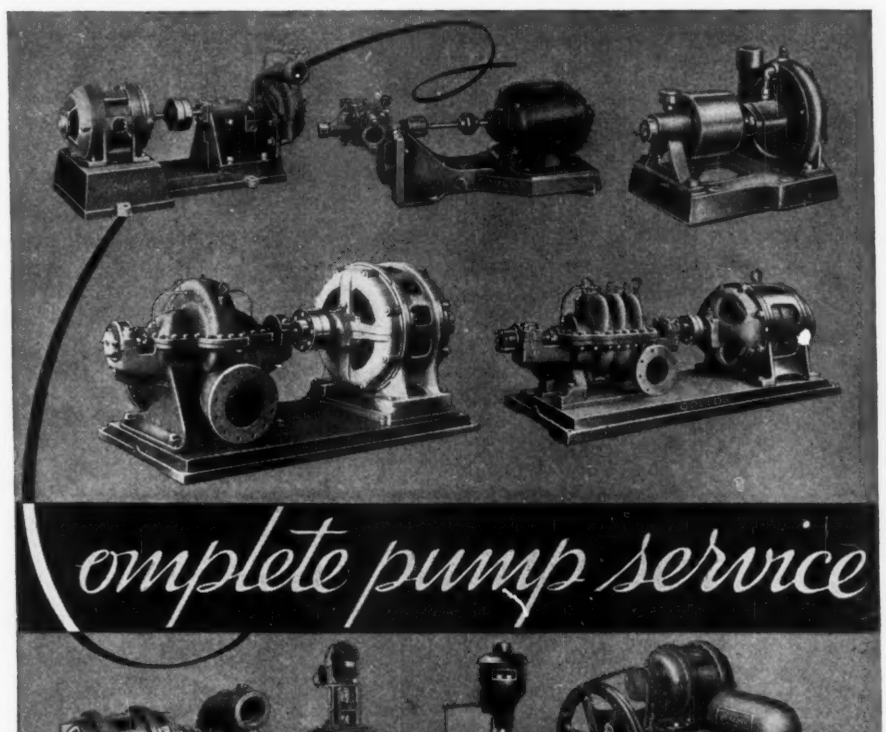
Count 20 points each for the correct answers to the following questions. Can you score 80? Don't look now, but the answers are on page 59.

1. The Great Barrier is the name you associate with:
   The Rocky Mountains — A famous nineteenth-century actor — A reef along the east coast of Australia — A prominent undertaker
2. Of course you know that Cleopatra's Needle is:
   A woman's magazine — An obelisk — A famous novel — A rock formation on the Nile
3. Only one of these boats has ever succeeded in completing two heats in the Harmsworth Trophy Race:
   The Estelle II — Excelsior France — Miss England II — Miss Britain III
4. The first automobile in the U. S. was built under a patent granted by:
   James A. Farley — The U. S. Patent Office — The State of Maryland — The U. S. Supreme Court
5. In what important places is Bundyweld Tubing used on most of today's automobiles?

The Answer to Your Tubing Problem is
BUNDY TUBING
BUNDY TUBING CO. . . . DETROIT

Consult the . . .
MECHANICAL CATALOG
1936-37 EDTIION
and see the catalog of
Goulds Pumps, Inc. on page 129

For your convenience we have placed a description of our products in the current Mechanical Catalog—
Your plant manager or engineer has the 1936-37 Edition



There is a Goulds for every industrial pumping need. Centrifugal pumps for low and high head operation with capacities from 10 to 15,000 g.p.m., piston type pumps, condensate return units, sump pumps, rotary pumps and diaphragm pumps. Out of the experience of nearly ninety years, each is designed for high efficiency operation that materially reduces pumping costs, and built for trouble-free day in and day out service.

To reduce pumping costs specify Goulds.

GOULDS PUMPS Inc.

ATLANTA, BOSTON, CHICAGO, HOUSTON, NEW YORK, PHILADELPHIA, PITTSBURGH, TULSA, Representatives in all Principal Cities

Built 30% Lighter with

USS MAN-TEN

Mine cage goes 800 feet deeper without increasing rope pull

WHEN the skips and double-deck cages for the El Potosi Mining Company of Mexico were built, the maximum rope pull limited the total hoisting distance to approximately 2,200 feet—as deep as they thought the mine would go.

Subsequent developments showed that the ore body extended down to the 3,000 foot level. How to compensate for the weight of the additional rope necessary, without scrapping the hoisting equipment, was a problem. USS MAN-TEN construction solved it. Built of MAN-TEN the new skips and cages are of the same capacity, but are 30% lighter than the old ones made of ordinary steel. Rope pull was not increased. The hoists handle the equipment as readily as before.

Vertical ore skip and double-deck hoisting cage of USS MAN-TEN. Built by the Allis-Chalmers Mfg. Company, Milwaukee, Wisconsin.

Are you lugging unnecessary dead weight around in your equipment? Trim it off with USS High Tensile Steels — USS MAN-TEN, USS COR-TEN, USS Stainless. Tougher and stronger—more resistant to shock, stress, fatigue, abrasion and wear—they offer every manufacturer the opportunity to cut down power consumption and replacement costs.

To find out how USS High Tensile Steels can be most economically applied to your designs, how little they increase cost, how readily they fabricate, write us.

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Columbia Steel Company, San Francisco, *Pacific Coast Distributors*

United States Steel Products Company, New York, *Export Distributors*

UNITED STATES STEEL

November, 1936 **MECHANICAL ENGINEERING CARD INDEX** VOL. 58, No. 11

PROFESSIONAL SERVICE

Consulting Engineers « Engineering Organizations « Constructors—Contractors « Patent Lawyers « Etc.

Representatives—Sales Agencies
Businesses For Sale
Partnership—Capital
Manufacturing Facilities

OPPORTUNITIES

Positions Open—Positions
Wanted—Equipment, Material,
Patents, Books, Instruments,
etc. Wanted and For Sale

RATES

Classified advertisements under this heading in MECHANICAL ENGINEERING are inserted at the rate of 60 cents a line, 50 cents a line to members of A.S.M.E. Seven words to the line average. A box number address counts as one line. Minimum insertion charge, 5 line basis, maximum 20 lines. Display matter carried in single column units of multiples of one inch a flat rate of $10. per inch per insertion. Copy must be in hand not later than the 10th of the month preceding date of publication.

POSITIONS OPEN

WANTED—Mechanical Draftsman with experience in high pressure Central Station piping and equipment layout work. State education, experience, salary desired and when available. Location—Southeast. Address CA-228, care of "Mechanical Engineering."

YOUNG MECHANICAL ENGINEER on production work—to start at bottom—good opportunity. Address CA-233, care of "Mechanical Engineering."

MECHANICAL ENGINEER—Experienced in design of deaerating equipment. All letters of application must include age, education, experience, and salary expected. All applications will be treated as strictly confidential. Address CA-234, care of "Mechanical Engineering."

EQUIPMENT FOR SALE

COMPLETE LARGE B & L METALLOGRAPHIC MICROSCOPE, inverted type with 8" X 10" Camera, optical equipment No. 12, complete set of additional lenses and items for macro work; stand and shock absorber; outfit is about four years old but hardly used; listed at approximately $1,600.00, will sell at $750.00. Write to: Spindler & Sauppe, Inc., 86 Third St., San Francisco, Calif.

INVENTIONS MAGAZINE

INVENTION & FINANCE MAGAZINE—Contacts interested manufacturers. Two years subscription ($1.00) entered on your promise to pay upon receipt of first copy. Invention & Finance, 80-P Wall Street, New York, N. Y.

POSITIONS WANTED

POWER PLANT or COMBUSTION ENGINEER, age 41, single, M.I.T. graduate desires new connection with public utility, industrial plant or manufacturer. 8 years consulting engineering, 10 years supervision of operation and maintenance large holding company. 3 years construction. Address CA-227, care of "Mechanical Engineering."

MECHANICAL ENGINEER—Member A.S.M.E., age 24, single, Cornell graduate. Desires to make change in engineering field, Interested in position in engineering department of a special process industry such as an oil refinery. Experimental testing, production testing, drafting and maintenance experience. Address CA-232 care of "Mechanical Engineering."

MECHANICAL ENGINEER, A.S.M.E. Member. Age 38, 22 years experience as mechanic, designer and engineering executive. Employed in locomotive stoker industry. Resourceful, inventive and a hustler. Has patent applications pending on some very likely products in the domestic stoker field. Desires to connect with progressive firm as assistant to a live-wire manufacturing executive. Address CA-230, care of "Mechanical Engineering."

SUPERINTENDENT—Mechanical Engineer and accountant. Age 37, married, 13 years experience in industrial engineering and managerial positions. Very broad experience. Desire change in position. Location wanted eastern United States. All replies regarded confidential. Address CA-229, care of "Mechanical Engineering."

EMPLOYMENT AGENCIES AND SERVICE BUREAUS

E. G. Stroud, Member A.S.M.E., President The Cleveland Engineering Agency Co., 219 Huron-Ninth Building, Cleveland, Ohio, has for 30 years been engaged in technical placement work. Employers wishing to engage Executives, Engineers, Designers, Draftsmen or other technical men are invited to use this service. Applicants available should write for blank and list of opportunities.

SALARIED POSITIONS
$2,500 to $25,000

This thoroughly organized advertising service of 26 years' recognized standing and reputation carries on preliminary negotiations for positions of the caliber indicated, through a procedure individualized to each client's personal requirements. Several weeks are required to negotiate and each individual must finance the moderate cost of his own campaign. Retaining fee protected by a refund provision as stipulated in our agreement. Identity is covered and, if employed, present position protected. If you have actually earned over $2,500, send only name and address for details. R. W. Bixby, Inc., 115 Delward Building, Buffalo, N. Y.

ENGINEERING SOCIETIES EMPLOYMENT SERVICE

Agency

CHICAGO OFFICE
Thomas Wilson, Manager
211 West Wacker Drive
Telephone State 2748

NEW YORK OFFICE
Walter V. Brown, Manager
Licensee
31 West 39th Street
Telephone PEnnsylvania 6-9220

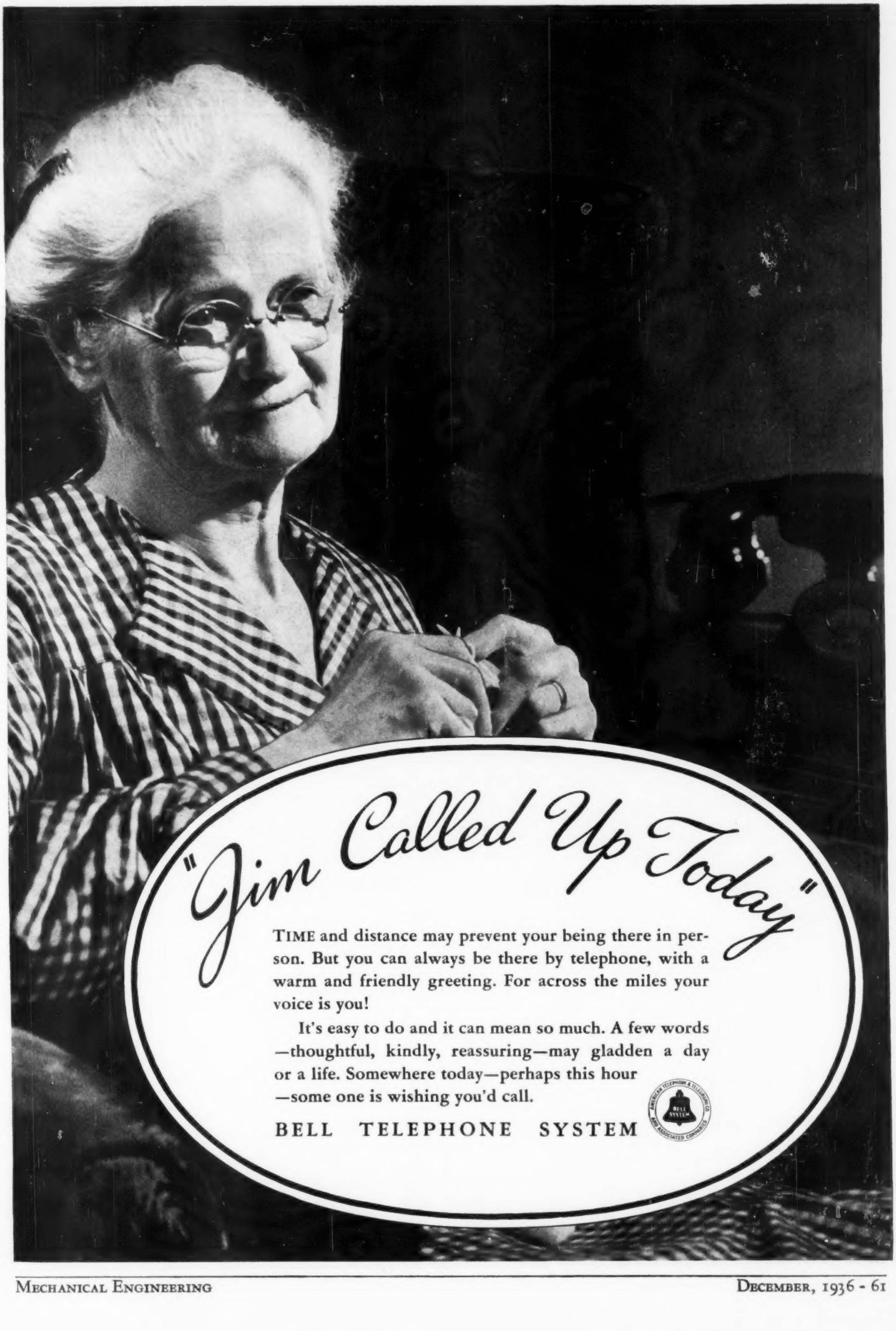
SAN FRANCISCO OFFICE
Newton D. Cook, Manager
57 Post Street
Telephone Sutter 1684

MECHANICAL ENGINEERS AVAILABLE

EMPLOYERS—The Engineering Societies Employment Service maintained by the four founder Engineering Societies as a service to the employer as well as to the employee, has available for immediate employment many well qualified and experienced engineers. Why not use this service for your own requirements and bring the service to the attention of your personnel, sales, advertising, purchasing, and other departments where technically trained men could be used to a decided advantage. Your non-technical departments probably are not acquainted with this service unless you tell them about it.

POSITIONS OPEN

The Service has a number of positions available for automatic machine as well as structural designers and draftsmen. A number of recent calls for Industrial Engineers experienced as well as recent graduates have considerably depleted our lists of available men in this field.


"Jim Called Up Today"
TIME and distance may prevent your being there in person. But you can always be there by telephone, with a warm and friendly greeting. For across the miles your voice is you!
It's easy to do and it can mean so much. A few words—thoughtful, kindly, reassuring—may gladden a day or a life. Somewhere today—perhaps this hour—some one is wishing you'd call.
BELL TELEPHONE SYSTEM

INDEX TO ADVERTISERS

The asterisk (*) indicates that firm has a product catalog in the 1936-37 MECHANICAL CATALOG

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Advertising forms of
MECHANICAL ENGINEERING
close on the sixth of the month preceding date of issue.

Space reservations for advertisement to appear in the January issue should reach us not later than December 6th, copy and cuts by December 10th.

This list gives the names of display advertisers in MECHANICAL ENGINEERING during 1936 including this issue. Where page number is omitted, it shows that the advertiser appeared in preceding issues.

Advertising in this issue handled by Agencies

Allis-Chalmers Mfg. Co. — *Stack-Goble Adv. Agency, Chicago, Ill.*
American Brass Co. — *Lord & Thomas, New York, N. Y.*
American Telephone & Telegraph Co. — *N. W. Ayer & Son, Philadelphia, Pa.*
Bakelite Corp. — *Rickard & Co., New York, N. Y.*
Bantam Ball Bearing Co. — *MacDonald-Cook Co., South Bend, Ind.*
Barco Mfg. Co. — *Evans Associates, Chicago, Ill.*
Charles Bruning Co. — *Buchen Co., Chicago, Ill.*
Bundy Tubing Co. — *Holden, Graham & Clark, Detroit, Mich.*
Carnegie-Illinois Steel Corp. — *Batten, Barton, Durstine & Osborn, New York, N. Y.*
Cleveland Worm & Gear Co. — *Paul Teas, Inc., Cleveland, Ohio*
Climax Molybdenum Co. — *N. W. Ayer & Son, Philadelphia, Pa.*
Crane Co. — *Chas. Daniel Frey Co., Chicago, Ill.*
De Laval Steam Turbine Co. — *George H. Gibson Co., New York, N. Y.*
Eugene Dietzgen Co. — *Geo. J. Kirkgasser & Co., Chicago, Ill.*
Garlock Packing Co. — *Hutchins Adv. Co., Rochester, N. Y.*
B. F. Goodrich Co. — *Griswold-Eshleman Co., Cleveland, Ohio*
Goulds Pumps (Inc.) — *O. S. Tyson & Co., Inc., New York, N. Y.*
Hyatt Roller Bearing Co. — *Campbell-Ewald Co., New York, N. Y.*
International Nickel Co. — *Marschalk & Pratt, New York, N. Y.*
Lukens Steel Co. — *G. M. Basford Co., New York, N. Y.*
Marlin-Rockwell Corp. — *Everett L. Bowers, Buffalo, N. Y.*
Nazel Engrg. & Machine Works — *R. E. Lovekin Corp., Philadelphia, Pa.*
Norma-Hoffmann Bearings Corp. — *L. I. Wightman, New London, Conn.*
Permutit Co. — *Kenyon & Eckhardt, New York, N. Y.*
Philadelphia Gear Works — *R. E. Lovekin Corp., Philadelphia, Pa.*
Phosphor Bronze Smelting Co. — *R. E. Lovekin Corp., Philadelphia, Pa.*
Republic Flow Meters Co. — *Evans Associates, Chicago, Ill.*
Revere Copper & Brass, Inc. — *Kenyon & Eckhardt, New York, N. Y.*
John Robertson Co. — *R. E. Lovekin Corp., Philadelphia, Pa.*
Shakeproof Lock Washer Co. — *Behel & Waldie, Chicago, Ill.*
Smooth-On Mfg. Co. — *A. Eugene Michel & Staff, New York, N. Y.*
Socony-Vacuum Oil Co. — *J. Stirling Getchell, New York, N. Y.*
Spring Washer Industry — *Neisser-Meyerhoff, Chicago, Ill.*
B. F. Sturtevant Co. — *Rickard & Co., New York, N. Y.*
Superheater Co. — *G. M. Basford Co., New York, N. Y.*
The Texas Co. — *Hanff-Metzger Co., New York, N. Y.*
Yarnall-Waring Co. — *McLain Organization, Philadelphia, Pa.*

Advertisers in Power Show Section

TEXACO AT WORK

brings many reports

like this...

Extract from Field Report
CUTTING OILS

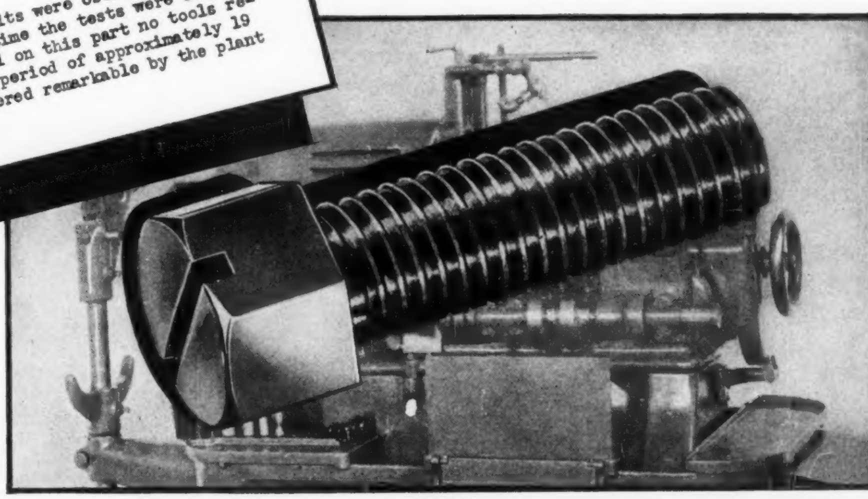
The next part to be selected for test of our oil was the machining of a screw for a clutch shaft made from 5/16 hexagon SAE 1020 steel.

The part is machined in a No. 00 Brown & Sharpe at a rate of 105 pieces per hour and with a surface speed of 122 feet per minute. The over-all length of the screw is 7/8" on which is cut a 12/32 thread.

With their present product extreme difficulties were encountered in producing a thread that was not torn.

After working with the die, steel, and machines for a period of approximately five hours decided to replace their present oil with Sultex Cutting Oil A. Immediately upon the use of this oil the torn and ragged threads disappeared and perfect threads were secured for eight hours.

On a second test good results were obtained for a period of 13 hours at which time the tests were concluded. During the test of our oil on this part no tools required re-grinding for a period of approximately 19 hours and this is considered remarkable by the plant personnel.



Here, in this group of oils, is new efficiency for cutters and grinders.

Texaco Sultex Cutting Oil—A

Texaco Sultex Cutting Oil—B

Texaco Sulfur Cutting Oil—A-2

Texaco Sulfur Cutting Oil—A-4

Texaco Cutting Oils

Texaco Soluble Oil—C

TEXACO
T
REG. T. M.

THIS test was performed in the presence of the Chief Metallurgist and Superintendent of the Automatic Department.

As a result of this and other tests Texaco Cutting and Soluble Oils were adopted as standard in this plant.

You, too, no matter what type of work you have, will find the same startling economies with these products. We advise you to make similar tests.

A Texaco representative will be glad to arrange for such tests and will provide practical engineering service to prove the economy of Texaco Cutting and Soluble Oils on your products.

THE TEXAS COMPANY
135 East 42nd St. · New York City
Nation-wide distribution facilities assure prompt delivery

THE NEW TEXACO *Cutting and Soluble Oils*

MRC 7309